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Coal/D-RDF (Densified Refuse Derived Fuel) Co-Firing Project, Milwaukee County, Wisconsin

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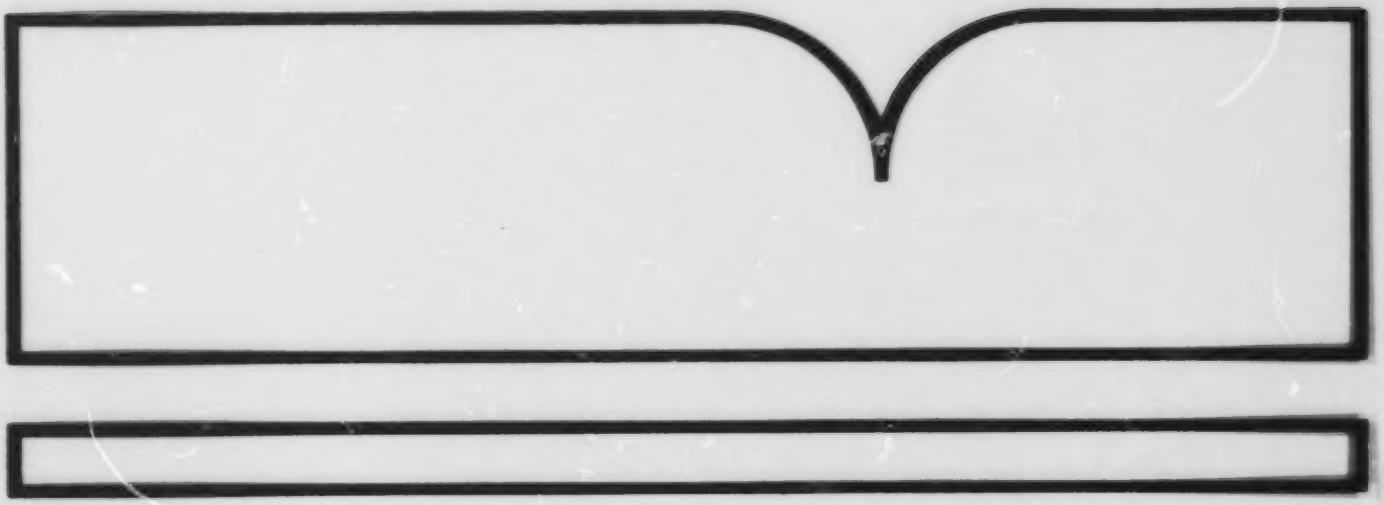

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November 1985

COAL/d-RDF CO-FIRING PROJECT
MILWAUKEE COUNTY, WISCONSIN

by

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16. ABSTRACT

A Research and Development Project was carried out to mix a densified refuse derived fuel with coal at the fuel receiving point and to co-fire the mixture in a spreader-stoker fired boiler. Two basic series of test runs were conducted. For the first series, coal was fired to establish a "base line" condition. For the second series, a mixture of coal and densified refuse derived fuel was fired. The report describes the equipment used to densify refuse derived fuel, procedures used to prepare and handle the coal and densified refuse derived fuel mixture and the test results. The results include the effect of the coal and densified refuse derived fuel mixture on plant operations, boiler efficiency, stack emissions and EP toxicity.

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Hazardous Waste Engineering Research Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs and regulations of the Environmental Protection Agency, the permitting and other responsibilities of State and local governments and the needs of both large and small businesses in handling their wastes responsibly and economically.

This project report discusses the performance of an industrial boiler when co-firingcoal and refuse-derived fuel. The parameters studied and tested were economics, operational characteristics, boiler efficiencies and stack emissions.

The information contained herein will be of interest fo those designers or users who are contemplating or working with a similar system. Requests for further information regarding the production and utilization of refuse-derived fuel should be directed to the Thermal Destruction Branch, HWERL, Cincinnati.

David G. Stephan, Director
Hazardous Waste Engineering Research Laboratory

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ABSTRACT

The potential for reduction in fuel cost impelled Milwaukee County to explore the possibility of supplementing coal with refuse derived fuel at the Milwaukee County Institutions' Power Plant.

A Research and Development Project was carried out to mix a densified refuse derived fuel with coal at the fuel receiving point and to co-fire the mixture in a spreader-stoker fired boiler.

Two basic series of test runs were conducted. For the first series, coal was fired to establish a "base line" condition. For the second series, a mixture of coal and densified refuse derived fuel was fired.

The report describes the equipment used to densify refuse derived fuel, procedures used to prepare and handle the coal and densified refuse derived fuel mixture and the test results.

The results include the effect of the coal and densified refuse derived fuel mixture on plant operations, boiler efficiency, stack emissions and EP toxicity.

This report was submitted in fulfillment of Grant No. R-806336-01-2 by Milwaukee County under the sponsorship of the U.S. Environmental Protection Agency. The report covers a period from October 1, 1978 to December 31, 1981, and the work was completed as of December 31, 1981.

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CONTENTS

Disclaimer ii
Foreword iii
Abstract iv
Figures viii
Tables x
Abbreviations & Symbols xi
Conversion Table xii
Acknowledgements xiii

1. Introduction 1
   - Inflating Fuel Cost 1
   - Americology 1
     - Light Fraction 1
     - Heavy Fraction 1
     - Dross 2
     - EPA Grant 2
     - Poor Dross Quality 2
     - Dross Firing Abandoned 2
   - Grant Modified for Densified RDF 2
2. Conclusions 4
3. Densification 6
   - Selection of Equipment 6
     - 390 Stationary Cuber 6
       - Modifications to Cuber 6
       - Observations in Kalispell 8
     - Americology Plant 8
       - Installation at the Americology Plant 8
       - Trial Program 8
   - Comments, Observations and Conclusions 15
     - Refuse Derived Fuel Particle Size 15
     - Cuber Feed Rate 15
     - Cuber Die Length 15
     - Refuse Derived Fuel Moisture Content 15
     - Use of Binder Material 18
     - General Conclusions 18
   - Establishing Cube Integrity 18
   - Quantity of Cubes Produced 19
   - Durability of Cuber 19
     - Die Durability 19
     - Press Wheel Durability 19
   - Potential for Further Use 21
4. Feeding 22
   - Transportation 22
   - Intent 22

CONTENTS (CONT'D.)

Fuel Handling at the Power Plant 22
Handling of d-RDF from Kalispell 22
Receipt of d-RDF from Americology 23
Deterioration of d-RDF 23
Tendency to Bridge 23
Operation of Reciprocating Feeder 23
Performance with d-RDF 23
Modifications to Reciprocating Feeder ... 28
Installation of Plastic Sheeting and Pneumatic Ram 28
Feed Rate Established 28
Operation on Belts 28
Operation in Bunkers 31
Mixing Trials 31
Results 31
5. Combustion and Steam Generation 34
Scales and Chutes 34
Arrangement of Test Boiler 34
Co-generation Power Plant 34
Air Pollution Control 34
Boiler Operation 37
Feed to Boiler 37
Tendency to Clinker 37
Unburned d-RDF 37
Particulate Carry-Over 37
Ash Handling 38
Load Carrying Ability 38
"Housekeeping" in the Power Plant 38
6. Test Program 39
Two Phase Program 39
Fuel Quality 39
Ash Quality 42
Boiler Performance 42
Emissions Testing 45
Mode of Operation During Test Program ... 46
Coal Used During Tests 46
May Tests 46
June Tests 46
Difficulty with Fuel Mix 51
Test Results 52
Boiler Performance 52
Efficiency Calculations 52
Efficiencies Summary 52
Particulate Emissions 59

CONTENTS (CONT'D.)

Particulate Entering the Precipitator 59
Particulate Leaving the Precipitator 59
Trace Metals 59
Opacity 59
Acid Dew Point 61
Gaseous Emissions 61
Sulfur Dioxide 61
Nitrogen Dioxide 61
Hydrogen Chloride 61
Electrical Characteristics 61
E.P. Toxicity 61
7. Post-Test Inspection 65

Appendices

A. 67
B. Co-Firing of Dross from a Refuse Derived Fuel Producing Plant with Coal on a Traveling Grate Spreader Stoker at Milwaukee County Institutions' Power Plant 69

FIGURES

Number		Page
1	The internals of a John Deere 390 Stationary Cuber	7
2	Special dies developed by Warren & Baerg Manufacturing	9
3	Installation of cuber at the Americology Plant	10
4	Americology Plant process	11
5	The modified John Deere 390 Stationary Cuber in operation	14
6	Worn press wheel and failed press wheel bolts after processing less than 400 tons of d-RDF	20
7	Receipt and handling of fuel at Milwaukee County Institutions' Power Plant	23
8	Milwaukee County Institutions' Power Plant showing coal conveyors, electrostatic precipitators and stacks	24
9	Delivery of d-RDF to Milwaukee County Institutions' Power Plant	26
10	Condition of d-RDF upon receipt at Milwaukee County Institutions' Power Plant	27
11	Modifications to reciprocating feeder adopted for the test program	29
12	d-RDF on one side of the reciprocating feeder dropping off to conveyor Belt A	30
13	Schematic arrangement of test boiler and air pollution control equipment	35
14	Schematic arrangement of Milwaukee County Institutions' Co-generation Power Plant	36
15	Schematic of test program	40

FIGURES (CONT'D.)

Number		Page
16	Steam flow chart - May 19, 1981 - coal firing	47
17	Steam flow chart - May 20, 1981 - coal firing	48
18	Steam flow chart - June 16, 1981 - coal/d-RDF mixture firing	49
19	Steam flow chart - June 17, 1981 - coal/d-RDF mixture firing	50
20	Coal Firing - Average Conditions - Three Runs - Summary Sheet	54
21	Coal Firing - Calculation Sheet	55
22	Coal/d-RDF Mixture Firing - Average Conditions - Three Runs - Summary Sheet	56
23	Coal/d-RDF Mixture Firing - Calculation Sheet	57
24	Plugged pin holes in travelling grate bar	66
1B	Americology Plant process at the time of the original Grant	71
2B	Analysis of dross	72

TABLES

Number		Page
1	Stack Emissions	5
2	Summary of Cube Product Trials	12
3	d-RDF Quality Summary	16
4	Coal/d-RDF Mixture Analyses	32
5	Fuel Comparison	41
6	Comparison of Fuel Ultimate Analyses	43
7	Ash and Unburned Combustible	44
8	Boiler Performance	53
9	Efficiency Comparison	58
10	Particulate Emission Comparison	60
11	Gaseous Emission Comparison	62
12	Particulate Electrical Characteristics - Precipitator Inlet	63
13	EP Toxicity	64
1B		72
2B		74

LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviations

ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
Btu	British thermal unit
d-RDF	densified refuse derived fuel
EPA	Environmental Protection Agency
EP toxicity	extraction procedure toxicity
ft	foot
hr	hour
KVA	kilovolt ampere
lb	pound
min	minute
psig	pounds per square inch, gage
RDF	refuse derived fuel
wt	weight

Symbols

CO_2	carbon dioxide
F	degrees Fahrenheit
Fe	iron
gr/scf	grains per standard cubic foot
$lb/10^6Btu$	pounds per million British thermal units
mg/l	miligrams per liter
N_2	molecular nitrogen
Ω-cm	ohm centimeters
O_2	molecular oxygen

CONVERSION TABLE

CONVENTIONAL INCH-POUND UNITS		S.I. UNITS
GIVEN →	MULTIPLY BY →	TO OBTAIN
inches	25.4	millimeters
feet	0.3048	meters
pounds	0.4536	kilograms
tons	0.9072	metric tons
Fahrenheit temperature (F)	(F-32) x 0.5556	Celsius temperature (C)
acres	0.4047	hectares
pounds per cubic foot	16.02	kilograms per cubic meter
pounds per square inch, gage	6.895	kilopascals (gage)
gallons	3.785	liters
British thermal units (Btu)	1055	joules
Btu's per pound	2.326	kilojoules per kilogram
pounds per million Btu	0.430	grams per megajoule
grains per standard cubic foot	2.291	grams per normal cubic meter
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ACKNOWLEDGEMENTS

The impetus for this Research and Development Project lay with the Incinerator Study Committee (a Subcommittee of the Committee of Energy, Environment and Extension Education of the Milwaukee County Board of Supervisors.) Members of the Incinerator Study Committee during the project have been:

Supervisor Fred N. Tabak, Chairman
Eugene J. Burns (Superintendent of the Milwaukee County Institutions' Power Plant)

Rudolf P. Pohl
Fred R. Rehm, P.E. (Director of Environmental Services)
Gerald Schwerm (Director of Public Works)

The Project Director for the County and the focus for the Project has been Mr. Rehm.

The Project Manager for the County has been Richard A. Keyes, P.E. His tireless efforts during the project design, trial and test program contributed enormously to the successful completion of the Project.

The cooperation of Mr. Burns and the operating staff at the Milwaukee County Institutions' Power Plant was an indispensable ingredient for success of this Project.

Finally, the staff at the Americology Plant cooperated fully in developing the Project and in providing densified refuse derived fuel. Major contributions were made by William J. Heine (Plant Manager), David E. Scholtz and David S. Hedlund.

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SECTION 1

INTRODUCTION

Milwaukee County, Wisconsin owns and operates an extensive County Institutions complex. The complex extends over 1000 acres. Energy needs are served by a co-generation power plant. The power plant produces electricity, heating steam and chilled water.

INFLATING FUEL COST

In an effort to control inflating energy costs, the County, in 1977, embarked on a program to determine the feasibility of using energy from refuse to supplant fossil fuels presently fired in the boilers at the power plant. To this end, the County Board of Supervisors established an Incinerator Study Committee.

AMERICOLOGY

Concurrently, the Americology Division of the American Can Company was developing and placing in operation a refuse processing and resource recovery facility in the City of Milwaukee. (The City of Milwaukee encompasses 38 percent of the area and 68 percent of the population of Milwaukee County.) The facility, known as the Americology Plant, was designed to receive municipal refuse from the City of Milwaukee and surrounding communities and process it to produce fuel and recyclable materials. The refuse derived fuel (RDF) was intended for use as a supplementary fuel in a large, pulverized coal-fired utility generating station.

Light Fraction

The RDF produced was expected to weigh about 50 to 60 percent of the incoming refuse weight. The light, fluff-like RDF fraction would consist largely of paper and light plastic.

Heavy Fraction

The remaining heavy material fraction was to be processed to remove metals and glass for recycling. The material left after processing for materials recycling was to be landfilled.

The landfilled material was expected to be largely wood, heavy plastic, rubber and other relatively dense, combustible materials.

The Abstract of a paper describing the development and operation of the Americology Plant is included as Appendix A.

Dross

It occurred to the Incinerator Study Committee that the heavy-combustible-materials destined for landfill from the Americology Plant could be suitable for co-firing with coal in the three, spreader-stoker-fired boilers at the County Institutions' Power Plant. This heavy fraction of combustible material was termed "dross" to differentiate it from the light fluff-like RDF.

EPA GRANT

In the summer of 1978, the County made application to the US Environmental Protection Agency (EPA) for a Research and Development Grant to demonstrate co-firing of dross with coal. The grant was approved in September of 1978.

Poor Dross Quality

It was quickly learned that the quality of dross was not as expected. Considerable metal and glass remained in the material and many oversize pieces were encountered. This precluded the possibility of pneumatically conveying dross. Modifications were made to the Americology Plant in an effort to improve the quality of dross. However, sustained improvement could not be achieved.

Dross Firing Abandoned

After extensive study, it was concluded that due to space limitations it was not practical to mechanically convey dross to the boilers. Therefore, co-firing of dross and coal was abandoned as a concept for demonstration.

Appendix B summarizes the efforts to develop the dross firing program under the initial EPA Grant Project.

GRANT MODIFIED FOR DENSIFIED RDF

Concurrent with these developments, Americology found that it was not possible to sell all of the RDF for use at the utility generating station. Americology determined that it could be practical to densify the light fluff-like RDF into integral shapes that could be mixed and co-fired with lump coal. This possibility was presented to the Incinerator Study Committee

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as an alternate Research and Development Project. Accordingly, in the summer of 1980, the scope of the Research and Development Project was converted from the co-firing of dross with coal to co-firing densified refuse derived fuel (d-RDF) with coal at the County Institutions' Power Plant.

This report summarizes the coal/d-RDF co-firing demonstration.

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SECTION 2

CONCLUSIONS

1. The modified John Deere 390 Stationary Cuber used in the project was not able to make cubes of refuse derived fuel on a sustained basis that could be relied upon to remain intact during transportation and handling.

2. The modified John Deere 390 Stationary Cuber used in the project experienced a wear rate and deterioration of parts that rendered the cuber unsuitable for extended use as a producer of d-RDF. Changes in metallurgy may be possible that will reduce wear rates to an acceptable level.

3. The coal/d-RDF mixture presented difficult handling and mixing problems with the available power plant equipment and resulted in a non-uniform mixture reaching the stoker. This condition resulted in erratic feeding of the refuse mixture with its resulting impact on the boiler steaming rate. Special attention will have to be given, in any future projects, to achieve and maintain a uniform coal/d-RDF mixture.

4. The low density d-RDF produced during the project, when mixed with coal, increased the specific volume of fuel (at a 20 to 25 percent d-RDF by weight mixture) to the point that the feeders on the test boiler had difficulty in maintaining 70 percent of rated boiler load.

5. The coal/d-RDF mixture tended to develop clinkers on the stoker grate more readily than the coal normally used at the Institutions' Power Plant.

6. At the firing rate experienced during the project (20 to 25 percent d-RDF by weight), there did not appear to be an adverse effect on stack emissions or EP Toxicity when compared to coal. See Table 1 for a comparison of stack emissions.

7. Additional developmental work will be required to reduce the high cost of cube production to make the produced d-RDF a competitive fuel compared with the cost of coal.

8. Additional developmental work will be necessary in order to improve d-RDF density so as to improve the handling and

firing of a coal/d-RDF mixture in conventional coal-handling and firing equipment.

TABLE 1

STACK EMISSIONS

	COAL	COAL/d-RDF MIXTURE
Particulate, lb/10^6 Btu	0.090	0.063
Sulfur Dioxide, lb/10^6 Btu	2.96	2.97
Nitrogen Dioxide, lb/10^6 Btu	0.44	0.49
Hydrogen Chloride, lb/10^6 Btu	0.063	0.206
Mercury Vapor, lb/10^6 Btu	<0.0000001	0.0000005
Aldehydes, lb/10^6 Btu	<0.001	0.004
Ketones lb/10^6 Btu	0.040	0.048
Acid Dew Point, F	295	305
Trace Metals		
Lead, lb/hr	0.0047	0.0077
Cadmium, lb/hr	0.0006	0.0058
Zinc, lb/hr	0.0286	0.0242
Mercury, lb/hr	0.00002	<0.00001
Beryllium, lb/hr	0.00004	0.00006

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SECTION 3

DENSIFICATION

SELECTION OF EQUIPMENT

Various machines and techniques for densifying refuse derived fuel have been proposed. After reviewing the various techniques available, the decision was made to concentrate on the feasibility of using a modified version of the John Deere 390 Stationary Cuber.

390 Stationary Cuber

John Deere has marketed this cuber since 1965, mostly in the West, to make cubes of alfalfa and other agricultural crops. The cubes which are one and one quarter inch square* in cross section are produced by forcing, cutting and shearing material through 66 concentric dies by means of an eccentric press wheel. Material is fed to the press wheel by means of an auger. See Figure 1 for a schematic representation of the auger, press wheel and dies. The material emerging from the dies comes in contact with a cube breaker ring and breaks off in pieces roughly one and one quarter inches long. Thus, pieces are termed "cubes."

Modifications to Cuber--

Alfalfa is a relatively uniform and light material when compared to refuse derived fuel (RDF). Consequently, modifications were required to adapt the 390 Stationary Cuber for RDF operation. The modifications include: 1) special dies and press wheel; 2) heavy duty end cap; 3) heavy duty clutch linkage; 4) oversized electric motor drive.

The densified RDF produced is termed d-RDF.

*The units of measure reported are as established by the equipment manufacturer, as read from instrumentation or as calculated. A conversion table to convert traditional inch-pound units to SI units (and vice versa) may be found on Page xii.

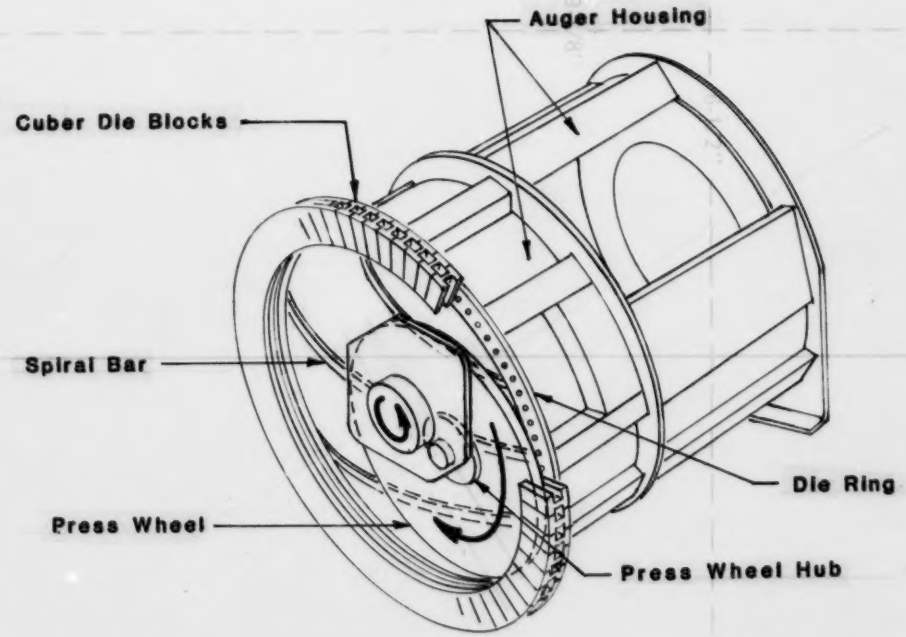

Figure 1. The internals of a John Deere 390 Stationary Cuber

Observations in Kalispell--

A modified 390 Stationary Cuber was observed cubing RDF at a lumbermill near Kalispell, Montana during September of 1980. Observations during the test program indicated that cubing ability was not uniform. Variation in cubes was apparently due to variations in moisture, as well as size and general make-up of the RDF feedstock. The RDF used during this observation had been shipped from the Americology Plant in Milwaukee, Wisconsin to Kalispell, Montana.

Based on the observations here and discussions with the manufacturers of the modified dies and press wheel, it was concluded that modifications to die geometry and metallurgy, along with careful control of RDF input, could result in acceptable cube production.

Americology Plant

Accordingly, Americology entered into a contract to purchase a modified 390 Stationary Cuber from Warren & Baerg Manufacturing of Dinuba, California. Concurrently, Milwaukee County entered into an agreement with Americology to lease, with a right to purchase, the cuber from Americology for the duration of the Research and Development Project. The configuration and metallurgy of the dies furnished by Warren & Baerg Manufacturing are shown on Figure 2.

Installation at the Americology Plant--

The cubing machine was installed as shown on Figure 3 in the Americology Plant. A feed chute was provided to divert a portion of the RDF at the point of plant discharge. Figure 4 is a schematic of plant processes to show the degree of processing to which the refuse was subject to produce RDF. Installation was completed on March 23, 1981 and the first d-RDF trials were conducted on March 26. Figure 5 is a photograph showing cubes emerging from the dies and accumulating at the bottom of the discharge chute.

Trial Program--

Five parameters were examined to determine impact on cube quality and integrity. These parameters were:

1. RDF particle size
2. Cuber feed rate
3. Cuber die length
4. RDF moisture content
5. Use of binder material

Twenty-seven trials were run during which these five parameters were adjusted and combined as tabulated in Table 2.

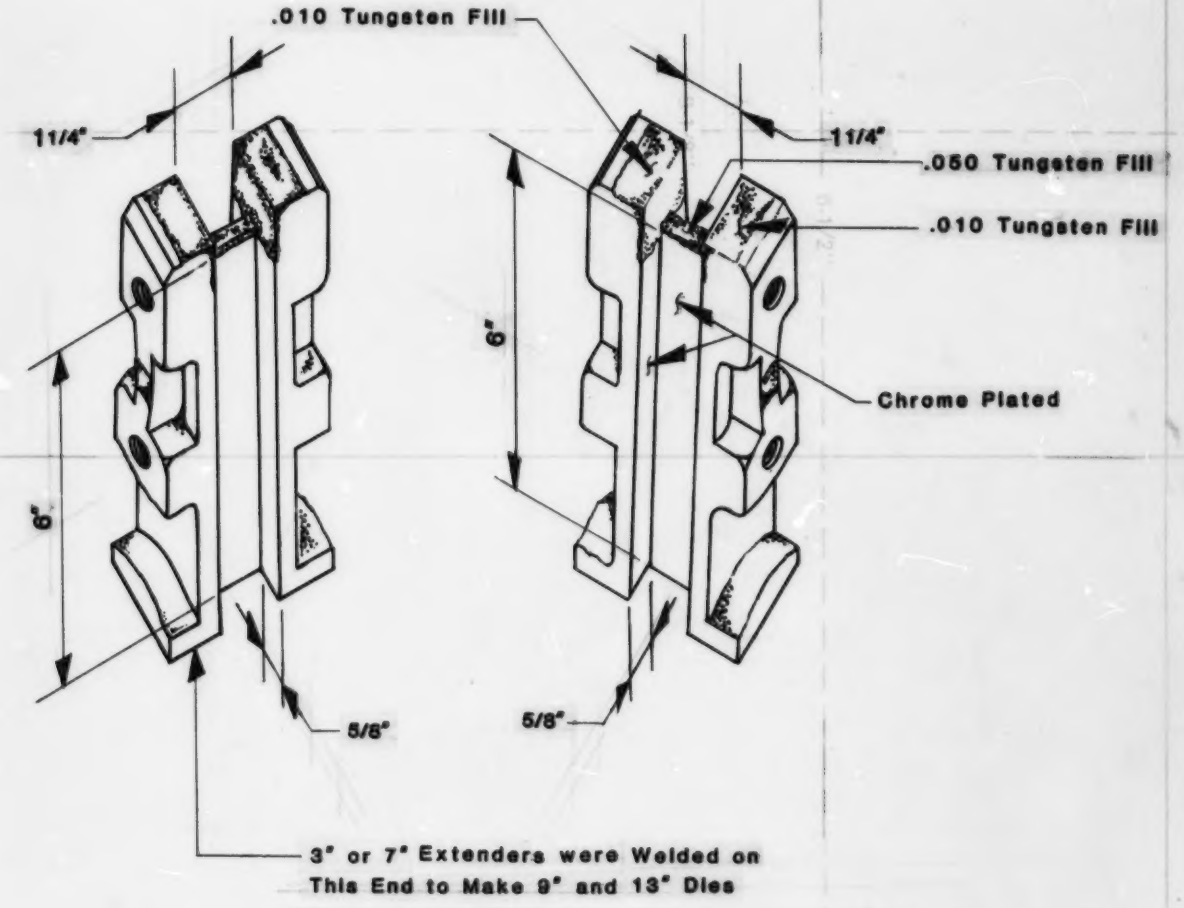

Figure 2. Special dies developed by Warren & Baerg Manufacturing

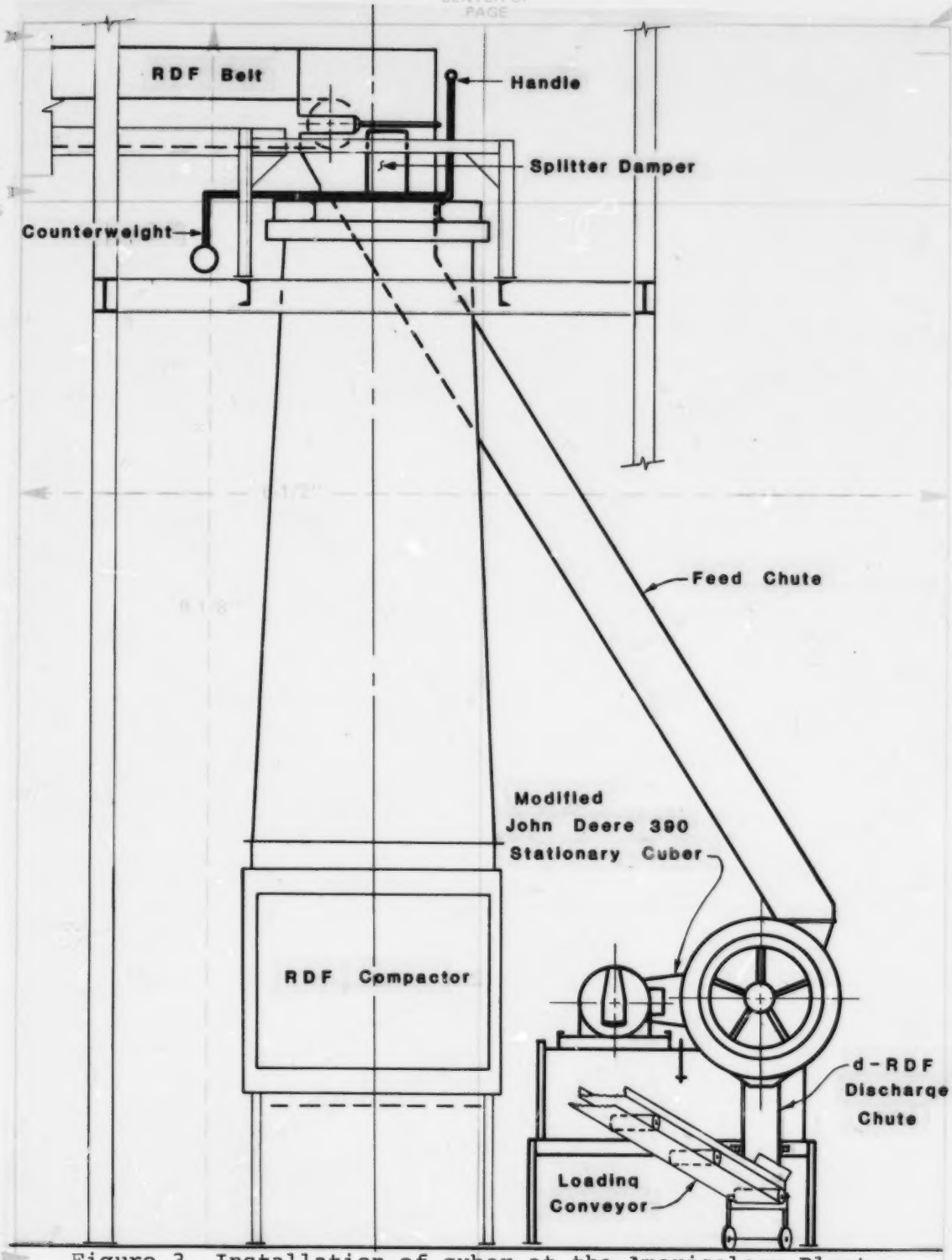

Figure 3. Installation of cuber at the Americology Plant

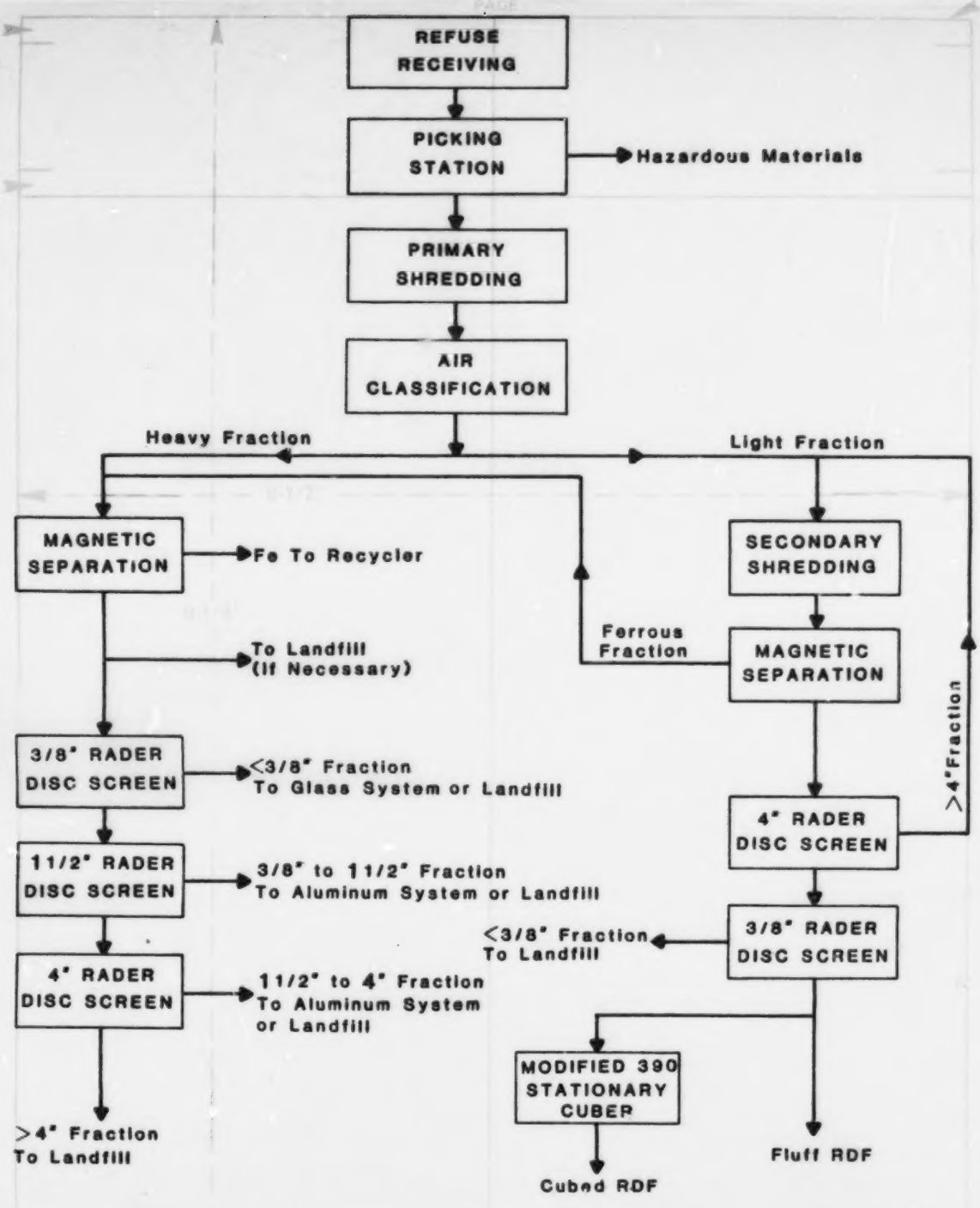

Figure 4. Americology Plant process

TABLE 2

SUMMARY OF CUBE PRODUCT TRIALS

TRIAL NO.	DATE	d-RDF PRODUCED (LBS.)	NOMINAL RDF PARTICLE SIZE (% 3/4")	AVERAGE FEED RATE (TONS/HR.)	DIE LENGTH (INCHES)	d-RDF MOISTURE (% WT.)	BINDER USED (% WT.)	OBSERVED CUBE QUALITY	COMMENTS
1	3/26	11,440	60.8	5.6	6	19.9	None	Good	
1a	3/27	11,100	67.5	6.36	6	26.1	None	Good	
2	3/30								Trial abandoned because of equipment malfunction.
3	3/30	12,020	70.5	7.8	6	21.5	None	Fair	Secondary shredder hammers modified.
3a	3/30	1,960	70.0	5.8	6	20.7	None	Fair	
4	3/31								Trial abandoned
5	3/31	4,960	72.7	5.7	9	25.9	None	Fair	
6	3/31	6,840	66.1	8.5	9	26.6	1.2-4.4	Fair-Good	
7	4/1	10,680	71.7	8.3	9	23.6	None	Good	Secondary shredder hammers modified
8	4/1	8,980	74.5	7.5	9	22.0	5%	Good	
9	4/7	10,140	41.4	3.6	9	15.7	None	Fair	
10	4/7	11,400	64.2	3.6	9	12.9	2.8%	Fair	Moisture added to RDF in an attempt to better activate binder.
11	4/9	22,600	64.8	3-4	9	23.6	None	Fair-Good	Secondary shredder hammers modified
12	4/13	11,060	50.4	3-4	9	20.2	None	Good	Cube breaker ring removed from cuber
13	4/14	11,160	69.2	3-4	9	19.0	2.9%	Good-very good	
14	4/15	18,400	*	3-4	9	31.9	None	Poor-Fair	Secondary shredder hammers modified
15	4/20	28,560	76.3	2.45	9	24.5	None	Poor-Fair	

TABLE 2 (CONTINUED)

SUMMARY OF CUBE PRODUCT TRIALS

TRIAL NO.	DATE	d-RDF PRODUCED (LBS.)	NOMINAL RDF PARTICLE SIZE (% 3/4")	AVERAGE FEED RATE (TONS/HR.)	DIE LENGTH (INCHES)	d-RDF MOISTURE (%WT.)	BINDER USED (% WT.)	OBSERVED CUBE QUALITY	COMMENTS
16	4/21	5,280	*	3-4	9	*	None	Good	Secondary shredder hammers modified
17	4/22	26,540	95.4	3.98	9	43.3	None	Good	
18	4/23	41,040	81.7	3.63	9	22.4	None	Good	
19	4/24	22,760	93.4	3-4	9	34.7	None	Good	
20	7/27	27,620	77.9	3-4	9	35.7	None	Fair	
21	4/29	34,220	89.5	3-4	9	24.8	11%	Poor	High % of grass clippings in RDF
22	4/30	29,340	*	3-4	9	*	None	Poor	High % of grass clippings in RDF
23	5/4	28,320	78.7	3-4	13	25.0	None	Fair-Poor	Secondary shredder hammers modified.
24	5/6	17,680	68.4	3-4	13	28.4	None	Fair-Poor	
25	5/7	26,920	95.1	3-4	13	34.2	None	Fair-Poor	
26	5/8	37,840	95.4	3-4	13	27.6	None	Fair-Poor	Secondary shredder hammers modified
27	5/11	Combined	77.7			35.5			

*Insufficient Data

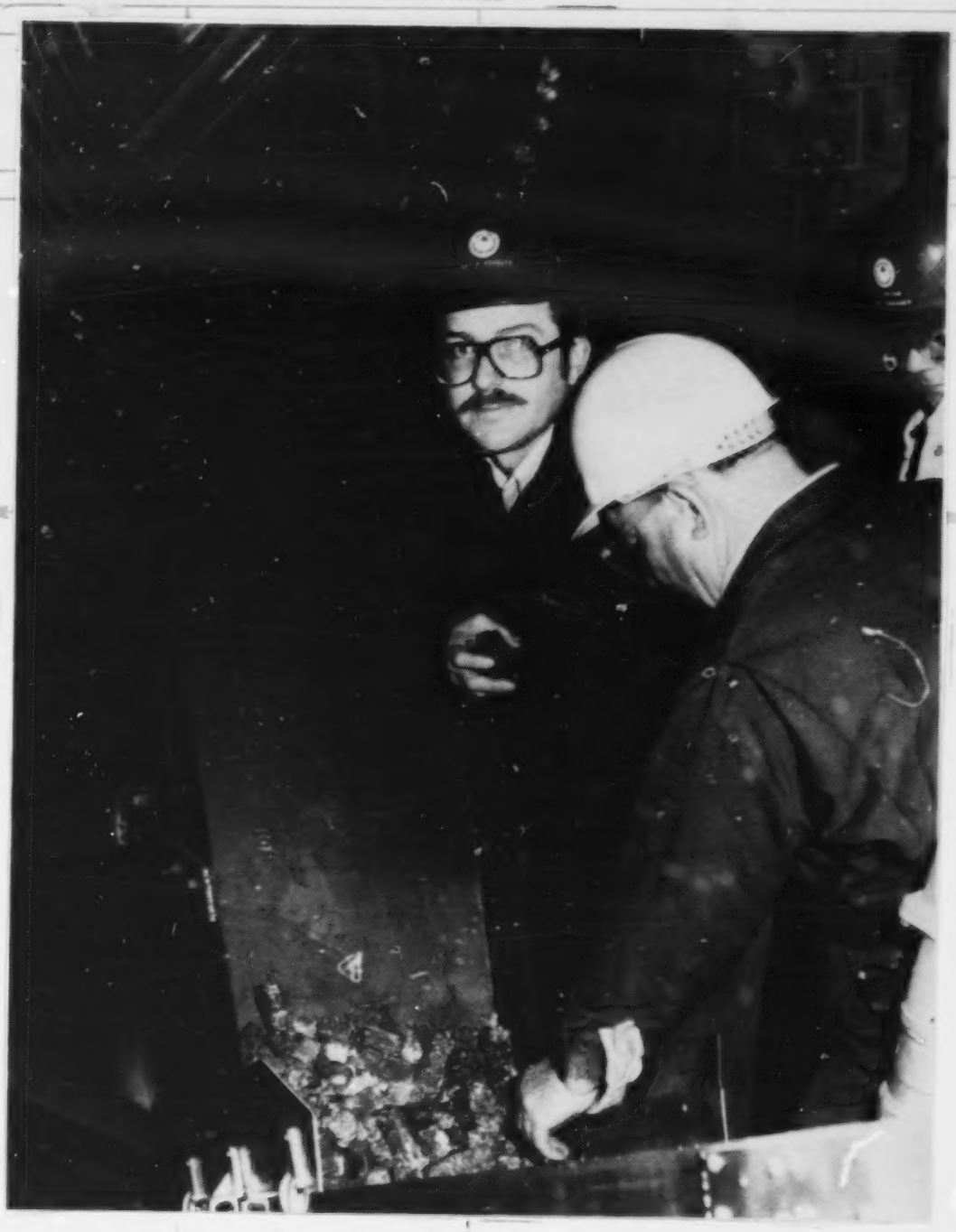

Figure 5. The modified John Deere 390 Stationary Cuber in operation. Note cubes emerging from dies above the head of the mustachioed attendant

COMMENTS, OBSERVATIONS AND CONCLUSIONS

Refuse Derived Fuel Particle Size

The early trial runs were made with RDF processed so that less than 45 percent passed through a three-quarter inch screen. On April 21, 1981 secondary shredder hammers were modified to produce RDF sized so that 90 percent would pass through a three-quarter inch screen. This degree of fineness was achieved or approached in most of the remaining runs. With finer feed material, an improvement in cube integrity could be visually observed.

Cuber Feed Rate

Cuber feed rates of up to 8-1/2 tons per hour were achieved during the early trial runs. It was quickly learned that a slower feed rate resulted in better d-RDF. From April 7 to the end of the tests, the feed rate was maintained below four tons per hour. It is believed that superior d-RDF quality is achieved because of increased "dwell" time in the dies at lower feed rates. (It was observed in Kalispell, Montana and at the trial runs in the Americology Plant that cubes tend to "set-up" if allowed to rest in the open air immediately after emerging from the cuber. Of course, it would have been impractical to do this at the Americology Plant without additional equipment. The cubes tended to break up during handling as they were transported from the cuber to storage.)

Cuber Die Length

The initial trial runs were accomplished using six inch long dies. On March 31 these were replaced by nine inch dies furnished by Warren & Baerg Manufacturing. The nine inch dies had been made by welding three inch extensions to six inch dies. While the nine inch dies were in use, Americology welded seven inch extensions (furnished by Warren & Baerg Manufacturing) to the original six inch dies to make 13 inch dies. The 13 inch dies were installed at the beginning of May and used until the end of the demonstration. With all other factors constant, the nine inch dies appeared to produce cubes of better integrity and firmness than the six inch dies. A further improvement in cube quality was not noticed when using 13 inch dies, however this may have been the result of excessive press wheel wear.

Refuse Derived Fuel Moisture Content

In general, the moisture content was "as produced". On occasions, when the RDF appeared to be particularly dry, water was sprayed on the material emerging from the secondary shredder. The moisture content data tabulated in Table 3 is for RDF sampled as it was fed to the cuber. The moisture content of the

TABLE 3
d-RDF QUALITY SUMMARY

DATE		RDF %MOISTURE	RDF %ASH	RDF %PASSING 3/4"	d-RDF %MOISTURE	d-RDF %ASH	d-RDF %ABOVE 1"	d-RDF BULK DENSITY (LBS/FT^3)	d-RDF ABSOLUTE DENSITY (LBS/FT^3)
3/26	11 a.m.	16.04	14.3	63.2	19.5	15.1	-	24.7	-
3/26	2 p.m.	18.4	16.7	58.4	20.2	13.8	-	-	-
3/27		23.6	18.0	67.5	26.1	18.8	-	24.0	-
3/30	#1	22.4	19.6	-	20.6	18.3	-	-	-
	#2	23.7	11.4	70.5	21.5	16.1	-	23.5	-
	#3	19.0	23.9	70.0	20.7	16.0	-	-	-
3/31	#1	22.8	24.3	72.7	25.9	19.5	-	24.8	-
	#2	23.5	17.6	66.1	26.6	19.4	-	29.3	-
4/1	#1	24.2	16.5	71.7	23.6	18.2	-	26.5	-
	#2	20.3	21.4	74.5	22.0	19.4	-	-	-
4/7	#1	16.9	13.1	41.4	15.7	10.5	93.2	24.0	-
	#2	16.3	18.3	64.2	12.9	10.3	85.6	25.0	-
4/9	#1	19.1	16.8	69.5	24.2	17.1	84.7	31.0	-
	#2	19.5	15.0	60.1	22.9	15.3	-	-	-
4/13	#1	16.1	14.9	50.4	18.7	18.6	96.1	34.5	-
	#2	-	-	-	21.6	28.7	93.3	35.0	-
4/14	#1	23.6	17.7	73.8	22.5	14.5	81.7	-	-
	#2	15.0	13.8	64.6	15.5	16.1	96.7	31.0	-
4/15		-	-	-	31.9	29.5	53.3	-	-

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TABLE 3 (CONTINUED)

d-RDF QUALITY SUMMARY

DATE	RDF %MOISTURE	RDF %ASH	RDF %PASSING 3/4"	d-RDF %MOISTURE	d-RDF %ASH	d-RDF %ABOVE 1"	d-RDF BULK DENSITY (LBS/FT^3)	d-RDF ABSOLUTE DENSITY (LBS/FT^3)
4/20	27.4	13.4	76.3	24.5	17.4	81.1	26.5	-
4/22	20.5	23.2	95.4	43.3	28.6	85.8	36.0	-
4/23	21.4	17.0	81.7	22.4	18.5	95.2	31.0	52.3
4/24	21.1	15.8	93.4	34.7	18.8	89.7	33.0	61.1
4/27	27.8	11.1	77.9	35.7	11.9	84.8	32.5	60.2
4/29	23.1	19.2	89.5	24.8	20.2	86.2	28.5	62.5
4/30	-	-	-	-	-	-	-	-
5/4	25.0	17.3	78.7	25.0	21.9	81.1	27.0	62.3
5/5	22.5	22.5	84.6	27.4	20.5	86.1	34.5	62.0
5/6	27.8	22.2	68.4	28.4	22.2	81.7	33.0	62.1
5/7	33.9	21.0	95.1	34.2	18.4	52.3	32.0	60.0
5/8	26.9	21.1	95.9	27.6	20.5	85.0	-	58.2
5/11	32.4	22.1	77.7	35.5	14.5	85.3	-	49.7
5/12	33.3	23.2	85.8	36.2	20.4	67.0	-	56.1
5/15	31.7	19.0	92.8	34.6	16.5	49.3	31.0	53.7
5/18	27.5	19.6	93.5	29.5	19.3	77.6	31.5	56.3
5/19	32.8	18.0	93.7	27.2	22.8	69.9	30.0	55.6
5/22	27.1	14.6	91.4	28.0	15.5	62.1	33.5	57.8
5/26	25.0	18.3	94.5	20.1	22.7	89.9	35.0	61.1
5/29	21.4	19.6	91.9	29.7	18.2	76.7	32.0	50.5
6/1	25.0	20.5	89.5	30.3	18.7	77.6	32.5	53.2

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d-RDF is for samples collected as it emerged from the cuber. As tabulated, the moisture content of the d-RDF tended to be higher than the moisture content of the RDF fed to the cuber. There is no explanation for this apparent increase in moisture content as no water was added to the material in the cuber. This anomaly is apparently a demonstration of the difficulty of obtaining representative samples of RDF and d-RDF.

Use of Binder Material

Because the cubes produced initially tended to break in handling and storage, it was presumed that the addition of a cohesive binder would improve cube integrity. Lignin sulfonate (a process by-product of the pulp and paper industry) is used as a binder in the manufacture of animal feed cubes and was selected as the binder for the trial runs. It appeared that the binder was useful in improving cube integrity when introduced at a high rate (on the order of 13 percent binder to 87 percent RDF by weight). Use of binder at such a high rate is so economically impractical that the use of binder was discontinued by the end of April.

General Conclusions

Operation of the cuber continued from March 26 through June 16, 1981. In mid-May, once it was felt that cubing capability could not be improved, no further changes were made to the five parameters for the remainder of the test period. The best results seemed to be obtained under the following conditions:

1. RDF particle size at 90 percent passing a three-quarter inch screen
2. Cuber feed rate maintained at three to four tons per hour
3. Use of 13 inch straight sided dies
4. No attempt made to add moisture in the cuber. Daily samples were taken and analyzed for moisture content.
5. No use of binder material.

ESTABLISHING CUBE INTEGRITY

A method was devised to rate cohesiveness or integrity of the cubes produced. A Gilson vibrating screen was fitted with one and one-half inch, one inch, three-quarter inch, half inch, one-quarter inch, and No. 10 sieve screen sizes and a pan. Grab samples of d-RDF weighing eight to ten pounds were placed on the vibrating screen and vibrated for three minutes. The weight of material from each screen was recorded and all material on or above the one inch screen was considered to be a cube. The percent of material above one inch was the measure of cube

integrity. Pertinent data for the various trials is recorded on Table 3. It should also be noted that the bulk density of the d-RDF was increased five to seven-fold in the cubing operation from the four to six pounds per cubic foot range of the fluff RDF.

It must be recognized that any system for grading or evaluating the quality or integrity of cubes produced is, to a large degree, subjective. In no case, either in Kalispell or at the Americology Plant, were good, consistent cubes produced free of uncubed material. Also, quality tended to vary during the course of a trial run due to changes in moisture content and composition of feed material.

QUANTITY OF CUBES PRODUCED

More than 380 tons of d-RDF were produced during the trial program. Of that quantity, nearly 130 tons were shipped to the Milwaukee County Institutions' Power Plant and co-fired with coal.

DURABILITY OF CUBER

Production of d-RDF was terminated on June 16 upon mechanical failure of the cuber press wheel. High press wheel wear had been observed while installing the 13 inch dies on April 30. Additional wear was observed on May 26 when the cuber was partially disassembled for maintenance. Press wheel wear appeared to cause extraordinary stresses on the press wheel assembly until, on June 16, the bolts which fastened the press wheel to the press wheel hub failed. Figure 6 is a photograph of the worn press wheel and failed bolts.

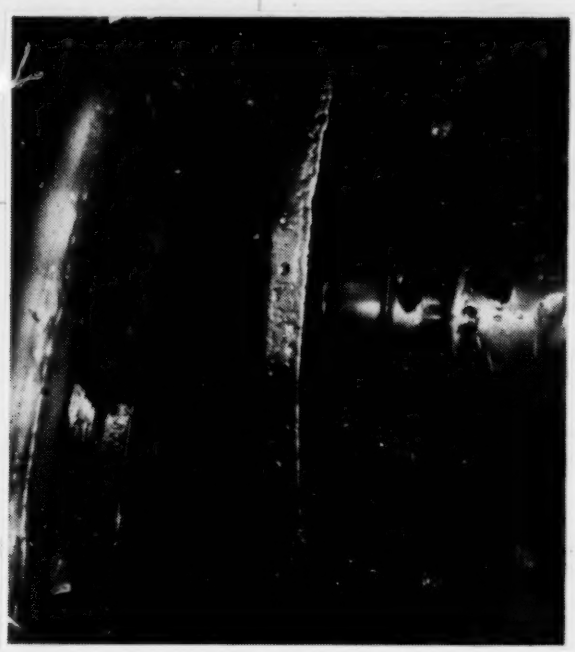
Cuber component wear was much higher than anticipated.

Die Durability

Twenty-five tons of material were processed initially with the original set of six inch dies and 202 tons were processed with the same dies after they had been extended to 13 inches. The total material processed with that set of dies was therefore 227 tons. The dies were so worn at the termination of the program that they could no longer be used. The nine inch dies used to process 166 tons of material were still serviceable.

Press Wheel Durability

Severe press wheel wear had been evident on April 30 after processing 185 tons. The press wheel was totally unserviceable after processing 387 tons. It now seems that it would have been advisable to replace the press wheel on April 30 as



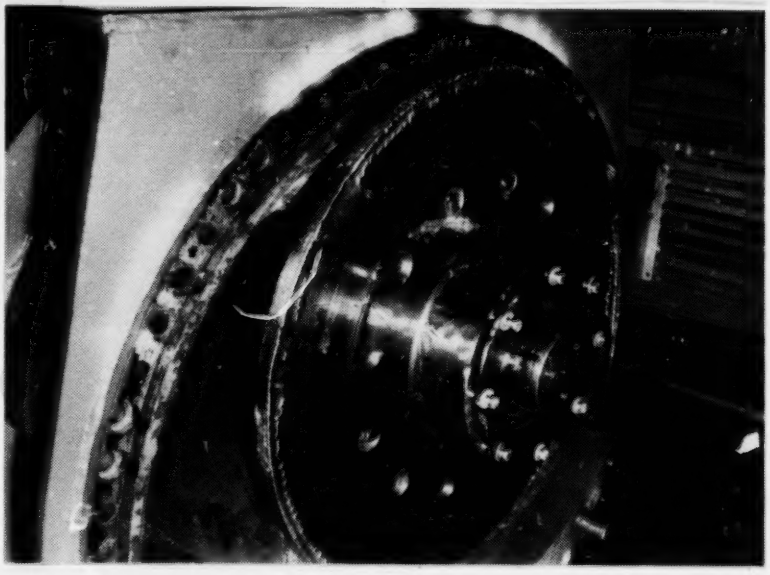


Figure 6. Worn press wheel and failed press wheel bolts after processing less than 400 tons of d-RDF

the quality of d-RDF fell rapidly from that point on as indicated in percent above one inch in Table 2. The cost of replacement parts for the press wheel and dies will exceed $8,000. This does not include installation costs.

POTENTIAL FOR FURTHER USE

Thus, the circumstances of this trial period indicate that cuber maintenance costs alone could exceed the value of d-RDF as a fuel. However, Americology personnel feel that metallurgic changes in the press wheel and dies could reduce maintenance costs to an acceptable level. Additional cuber components will be purchased and further trials conducted by Americology beyond the scope of this grant program.

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SECTION 4

FEEDING

TRANSPORTATION

The d-RDF produced at the Americology Plant was transported by truck to the County Institutions' Power Plant.

INTENT

The intent of the Research and Development Program was to blend coal and the d-RDF at the fuel receiving hoppers and transport the mixture to the coal bunkers.

FUEL HANDLING AT THE POWER PLANT

The fuel receiving and transport system is shown schematically in Figure 7. In normal operation, coal is received in 20 to 25 ton truck loads, dumped through a four inch square grizzly screen into two feed hoppers where a reciprocating feeder discharges the coal from the two hoppers on a moving belt. The moving belt (Belt A) transports the coal from below grade to a transfer tower where it is dumped on a second belt (Belt B) located, in plan, at 90 degrees to the first belt. The second belt conveys the coal upward to the moveable tripper which trips the coal into selected coal bunkers. There are three bunkers, one for each of the three coal fired boilers. Each bunker has two bottom outlets. The coal receiving point, Belt A conveyor, transfer tower and Belt B conveyor can be seen at the left hand side of Figure 8. The three recently installed electrostatic precipitators, one for each coal fired furnace, may also be seen at the rear of the power plant.

Handling of d-RDF from Kalispell

Three 55 gallon drums of d-RDF were shipped back from Kalispell, Montana in September of 1980. In a brief demonstration, the material in the three drums was dumped into one of the two feed hoppers while coal was placed in the other hopper. The d-RDF fed out of the hopper without difficulty. It was recognized, however, that the three 55 gallon drums of d-RDF did not constitute a rigorous test, but merely demonstrated that co-feeding of coal and d-RDF was feasible.

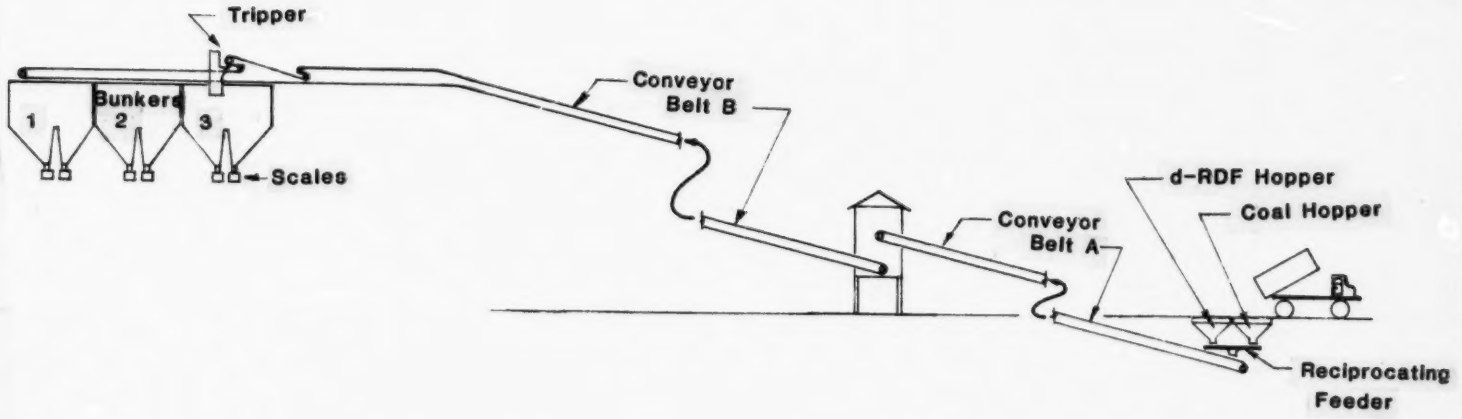

Figure 7. Receipt and handling of fuel at Milwaukee County Institutions' Power Plant

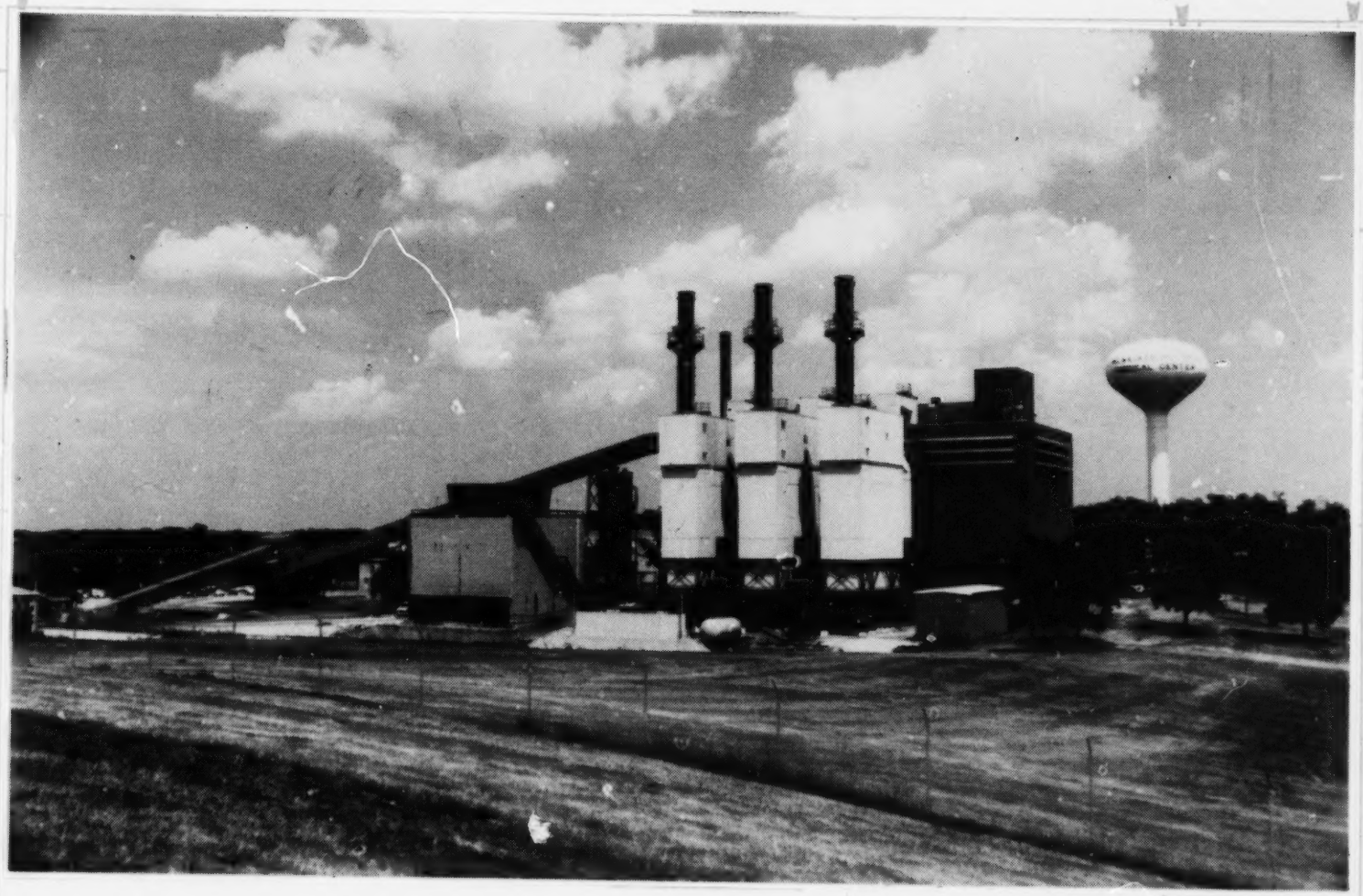

Figure 8. Milwaukee County Institutions' Power Plant showing coal conveyors, electrostatic precipitators and stacks

Receipt of d-RDF from Americology

Once the cuber was set-up at the Americology Plant and d-RDF was produced, further demonstrations of co-feeding were undertaken. The first attempt, on April 6, 1981, was accomplished by filling one hopper with coal and introducing d-RDF into the other hopper. In order to utilize one hopper for d-RDF, the grizzly screens were removed as it seemed certain that the d-RDF would tend to bridge over the screen openings much more readily than coal. Figure 9 shows a truck dumping d-RDF into the receiving hopper with the grizzly screen removed.

Deterioration of d-RDF

The d-RDF delivered to the Institutions' Power Plant contained a large percentage of material that was no longer in cube form. Handling and transport of the material obviously had resulted in many of the cubes breaking apart. As material was dumped from the truck into the hopper, quantities of dust and light material were blown around the area. In a permanent installation for continuous operation, this would be a serious problem. Typical d-RDF as received at the Power Plant is pictured in Figure 10.

Tendency to Bridge

It readily became apparent that there was a great tendency for the d-RDF material to "bridge" in the hopper. In order to feed the material, continuous manual rodding was required.

Operation of Reciprocating Feeder

The reciprocating feeder has a six inch stroke. In normal operation, the bed of coal on the feeder plate is fed forward six inches on the forward stroke; and then back almost three inches as the plate slides back under the coal. Thus, the coal could be observed moving 30 inches forward during nine strokes of the feeder.

Performance with d-RDF--

On the d-RDF side of the feeder, the refuse was observed to move forward the full six inches with each stroke of the feeder; but then it retracted almost the full six inches. Thus, it took 40 to 60 strokes of the feeder to move d-RDF 30 inches.

It became clear that without some means of preventing retraction of d-RDF on the reciprocating feeder, it would be impractical to co-feed coal and d-RDF so that d-RDF represented a significant proportion of the total energy input.

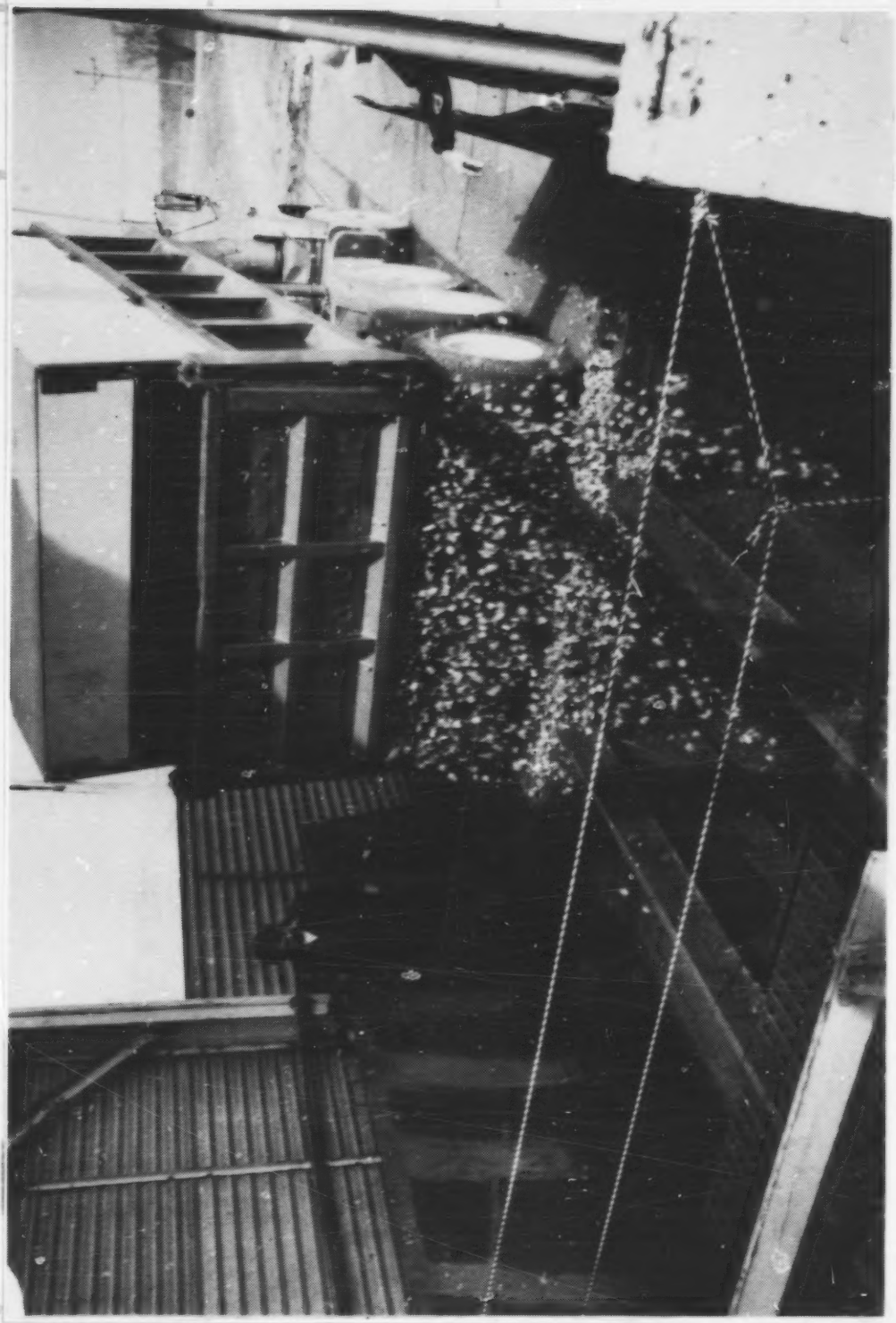

Figure 9. Delivery of d-RDF to Milwaukee Institutions' Power Plant

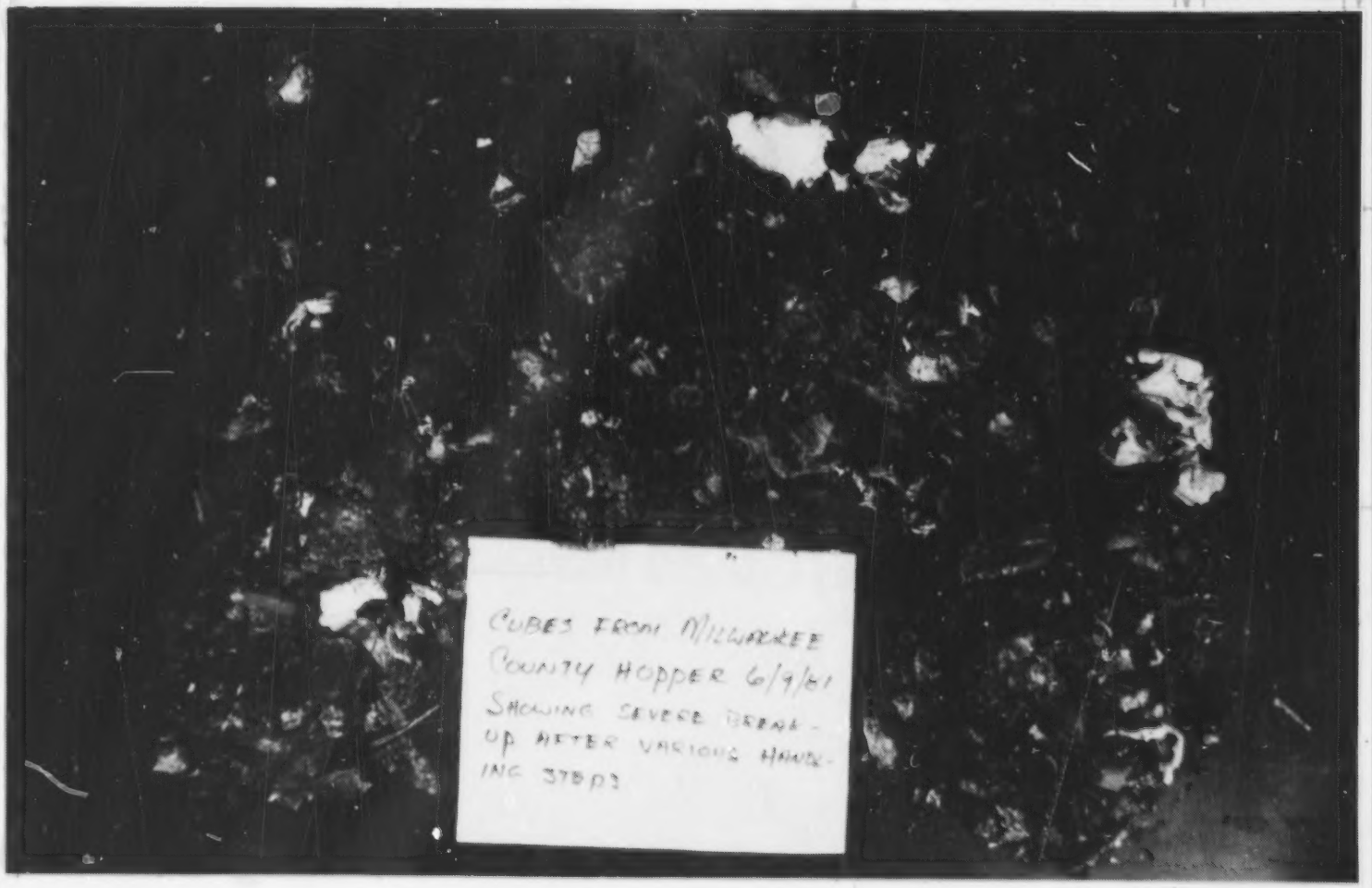

Figure 10. Condition of d-RDF upon receipt at Milwaukee County Institutions' Power Plant. Note condition of d-RDF relative to Figure 5.

Modifications to Reciprocating Feeder

A number of modifications were made to produce a more positive forward feed of d-RDF. Most of the attempts resulted in little or no significant improvement. It should be noted however that because of the overall needs of the power plant, the project team was not permitted to make major modifications to the hopper configuration or feeder operation.

Installation of Plastic Sheeting and Pneumatic Ram--

After several attempts, the arrangement depicted in Figure 11 was adopted for use during the balance of the project. The modifications included erecting a temporary vertical plywood baffle at the discharge end of the hopper opening, and covering the hopper sides, including the temporary baffle, with 1/4 inch thick ultra-high-molecular-weight, polyethylene plastic sheeting to reduce the co-efficient of friction between the hopper sides and d-RDF. This arrangement, along with care in regulating the flow of d-RDF from the dump truck into the hopper, reduced the bridging problems in the hopper. The most significant modification to the feeder was the temporary installation of a pneumatically driven ram to effect a controllable, positive motion of d-RDF toward the feeder outlet. Both the length and the rate of the stroke of the pneumatic ram were adjustable to provide control of the d-RDF feed rate. A coal metering gate was installed to reduce the flow on the coal side, if necessary.

Figure 12 is a photograph showing d-RDF on the reciprocating feeder. Flow of the d-RDF is from the left to the drop off point to conveyor Belt A.

Feed Rate Established--

With these modifications, a coal/d-RDF mixture in which the energy from refuse approached 15 percent of the total boiler energy input was achieved. This level of boiler energy input was not as high as anticipated for the project; but it seemed to be the maximum that could be achieved without major modifications to the power plant coal feed equipment.

Operation on Belts

Once the coal/d-RDF mixture was on the conveyor belts, the material moved without difficulty to the bunkers. It should be noted however that dust from d-RDF increased housekeeping problems in the conveyor housing areas.

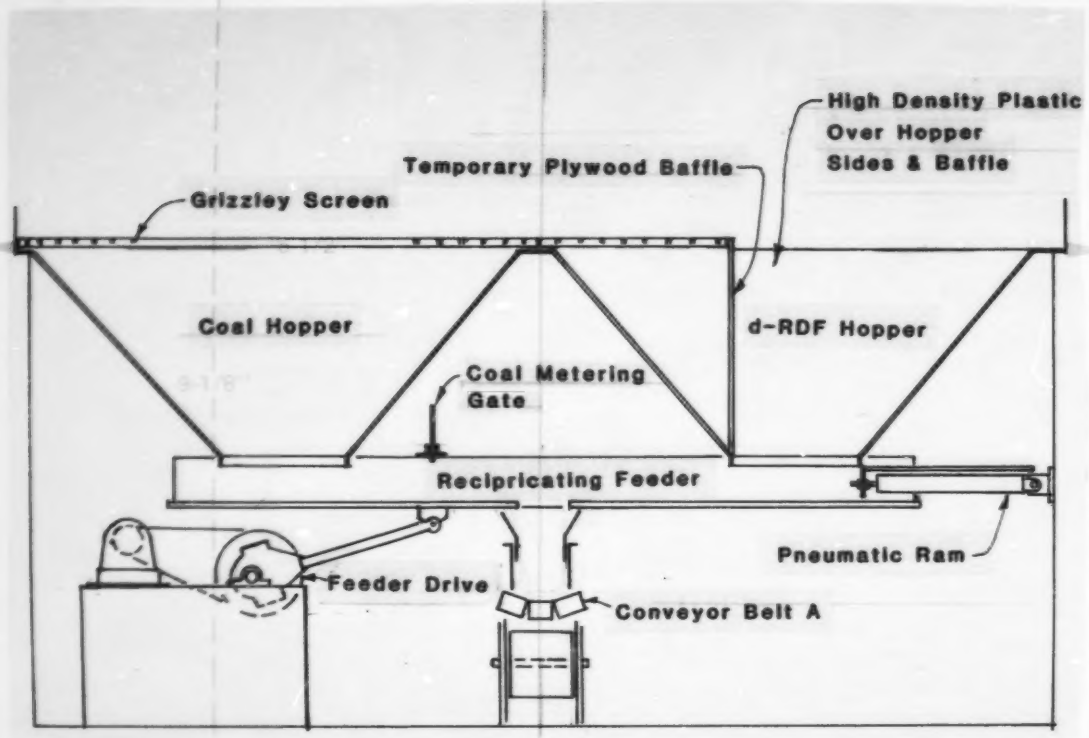

Figure 11. Modifications to reciprocating feeder adopted for the test program.

Figure 12. d-RDF on one side of the reciprocating feeder dropping off to conveyor Belt A. Note condition of d-RDF relative to Figure 5.

Operation in Bunkers

Although the coal and d-RDF appeared to be well mixed on the conveyor belts, there appeared to be a tendency for the two fuels to demix in a layered manner as it fell into the bunkers. This was perhaps due to the difference in density and aerodynamic configuration of the two fuels. Thus, throughout the field test program, substantial variations in coal to d-RDF ratios were experienced at the bunker outlets. The apparent non-homogenity of the coal/d-RDF mixture observed at the scales may also have been a result of filling the bunker with a high percentage of d-RDF on June 10 and the subsequent bridging and rat-holing during the balance of the project.

MIXING TRIALS

A coal/d-RDF mixture was continuously fired in Boiler 3 from June 9 through June 17.

During that period, samples of the mixture were regularly gathered at the point where the mixture fell from the tripper into the bunker and at the two scales at the bunker outlets. The samples were hand-sorted to determine the mix of coal and d-RDF by weight. The results are summarized in Table 4.

Results

As a result of the trials and operating experience at the boiler, the June 12 settings were established for the remainder of the program. The pneumatic ram was set at three strokes per minute and the coal metering gate was left in the open position.

TABLE 4

COAL/d-RDF MIXTURE ANALYSES

Sample No.	Date	Time	Coal Metering Position	Ram Speed (Strokes/Min.)	Sample Location	Coal (lbs.)	d-RDF (lbs.)	Combined Sample	% d-RDF by weight	Density (lb/ft^3)
1	6/9	1330	Open	Variable	Tripper	39.5	3.5	43.0	8.1	-
2	6/9	1500	#4	6½	Tripper	8.25	7.5	15.75	47.6	-
3	6/9-10	1620-?	-	-	Scales	25.5	5.0	30.5	16.4	-
4	6/9-10	?-0700	-	-	Scales	22.5	7.0	29.5	23.7	-
5	6/10	1000	#4	4	Tripper	7.0	4.0	11.0	36.4	-
6	6/10	1120	#4	6½	Tripper	11.5	6.5	18.0	36.1	-
7	6/10	1140	#4	6½	Tripper	10.75	5.75	16.5	34.8	-
8	6/10	1415	#4	6½	Tripper	9.25	7.25	16.5	43.9	-
9	6/10	1510	#4	6½	Tripper	6.5	9.0	15.5	58.1	-
10	6/10-11	?	-	-	Scales	17.0	7.5	4.5	30.6	-
11	6/10-11	?	-	-	Scales	7.5	5.0	12.5	46.0	-
12	6/11	0800-1030	-	-	Scales	11.25	8.5	19.75	43.0	-
13	6/11	1045-1200	-	-	Scales	5.125	5.75	10.875	52.9	-
14	6/11	1140	Open	3½	Tripper	10.5	3.5	14.0	25.0	-
15	6/11	1320	Open	3½	Tripper	10.5	2.25	12.75	17.6	-
16[4]	6/11	1230-1430	-	-	Scales	16.25	3.0	19.25	15.6	-
17	6/11	1500-1800	-	-	Scales	10.0	1.0	11.0	9.1	-
18	6/11	1900-2200	-	-	Scales	6.75	1.75	8.50	20.6	-
19	6/11-12	2300-0200	-	-	Scales	15.0	3.75	18.75	20.0	-
20	6/12	0300-0600	-	-	Scales	21.0	1.5	22.5	6.7	-
21	6/12	0700-0800	-	-	Scales	6.75	0.75	7.5	10.0	-
22	6/12	0940	Open	3	Tripper	13.0	5.0	18.0	27.8	-
23	6/12	1110	Open	3	Tripper	10.0	6.0	16.0	37.5	-
24	6/12	1100-1500	-	-	Scales	16.0	2.0	18.0	11.1	-
25	6/12	1600-1800	-	-	Scales	16.0	6.5	22.25	28.9	-
26	6/13	-	Open	3	Estimate	44000	17020	61020	27.9	-
27†	6/15	0800	Open	4	Tripper	7.5	3.5	11.0	31.8	-
28	6/15	0910	Open	3	Tripper	6.625	5.0	11.625	43.0	21.5
29	6/15	1035	Open	3	Tripper	12.0	5.0	17.0	29.4	-
30	6/15	1155	Open	3	Tripper	13.5	6.125	19.625	31.2	-
31	6/15	1300-1800	-	-	Scales	16.0	6.5	22.5	28.9	46.5

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TABLE 4 (CONTINUED)

COAL/d-RDF MIXTURE ANALYSES

Sample No.	Date	Time	Coal Metering Position	Ram Speed (Strokes/Min.)	Sample Location	Coal (lbs.)	d-RDF (lbs.)	Combined Sample	% d-RDF by weight	Density (lb/ft^3)
32	6/15	1900-0000	-	-	Scales	14.25	6.0	20.25	29.6	40.0
33	6/16	0100-0600	-	-	Scales	12.5	2.5	15.0	16.7	43.25
34♦§	6/16	0700-0900	-	-	Scales	12.5	0.5	13.0	3.8	62.0
35	6/16	0800	Open	3	Tripper	11.5	5.5	17.0	32.4	23.75
36§	6/16	1000-1200	-	-	Scales	5.75	2.25	8.0	28.1	-
37	6/16	-	Open	3	-	-	-	-	-	-
38♦	6/16	1300-1500	-	-	Scales	8.5	2.0	10.5	19.0	-
39	6/16	1300	Open	3	-	12.5	6.0	18.5	32.4	-
40♦	6/16	1500-1800	-	-	Scales	17.25	6.0	23.25	25.8	-
41	6/16	1900-0000	-	-	Scales	4.25	2.0	6.25	32.0	-
42	6/17	0100-0600	-	-	Scales	16.0	6.75	22.75	29.7	-
43∇	6/17	0700-0900	-	-	Scales	11.75	4.5	16.25	27.7	40.75
44	6/17	0830	Open	3	-	12.5	11.5	24.0	47.9	33.0
45∇	6/17	1000-1200	-	-	Scales	9.5	3.0	12.5	24.0	-

* Sample taken after feeding approximately 46 tons of coal into rat holes in d-RDF. Coal was added to the fuel mixture in bunker number 3 between about 1000 and 1132 hours to enrich mixture to stokers. Boiler began recovery about 1200 hours and returned to normal operation about 1300 hours.

† d-RDF consisted of a higher percentage of cubes than any loads delivered to date during this test sequence. Cubes appeared to have best integrity and co-hesiveness of any d-RDF delivered to date.

♦ Operator verbally reported occurrence of severe rat holing in number 3 bunker. No fuel flowing from bunker to number 6 scale. Coal was transferred from number 1 bunker for a couple of hours during the later part of the 2300-0700 shift.

§ Samples 34 and 36 were averaged for coal/d-RDF Run 1.

♦ Samples 38 and 40 were averaged for coal/d-RDF Run 2.

∇ Samples 43 and 45 were averaged for coal/d-RDF Run 3.

SECTION 5

COMBUSTION AND STEAM GENERATION

SCALES AND CHUTES

Fuel from the bunkers is fed through two gravimetric weigh scales to two conical chutes. Each conical chute feeds two Hoffman spreader stokers. There are a total of four spreaders for each furnace and there are a total of three identical coal fired furnaces and boilers in the Institutions' Power Plant. Boiler #3 was selected for the coal/d-RDF cube firing test.

ARRANGEMENT OF TEST BOILER

Figure 13 is a schematic of the firing equipment, steam generating equipment and air pollution control equipment for Boiler #3. Steam is generated at 610 psig and approximately 725 F. (Attemporators or other means of steam temperature control are not included in the system.) The three Union Iron Works boilers are rated at 110,000 pounds of steam per hour with peaking capability at 125,000 pounds per hour. They were installed in 1954.

CO-GENERATION POWER PLANT

The steam is used to drive two 3750 KVA back-pressure turbine generators, one 6250 KVA condensing turbine generator, chiller system auxiliaries and other plant auxiliaries. Extraction points from the turbine generators or a pressure reducing station are used to feed a 135 psig, 550 F heating system. Exhaust from the back pressure turbines or from a pressure reducing station is used to feed 15 psig absorption water chillers and a 15 psig heating system. Thus the County Institutions' Power Plant is a co-generation system producing electrical energy, high and low pressure heating steam and chilled water. The system is shown schematically on Figure 14.

AIR POLLUTION CONTROL

Gas cleaning for each coal fired boiler is accomplished by a mechanical collector followed by a three-field electrostatic precipitator. The standard for particulate emissions as established by the Wisconsin Department of Natural Resources for

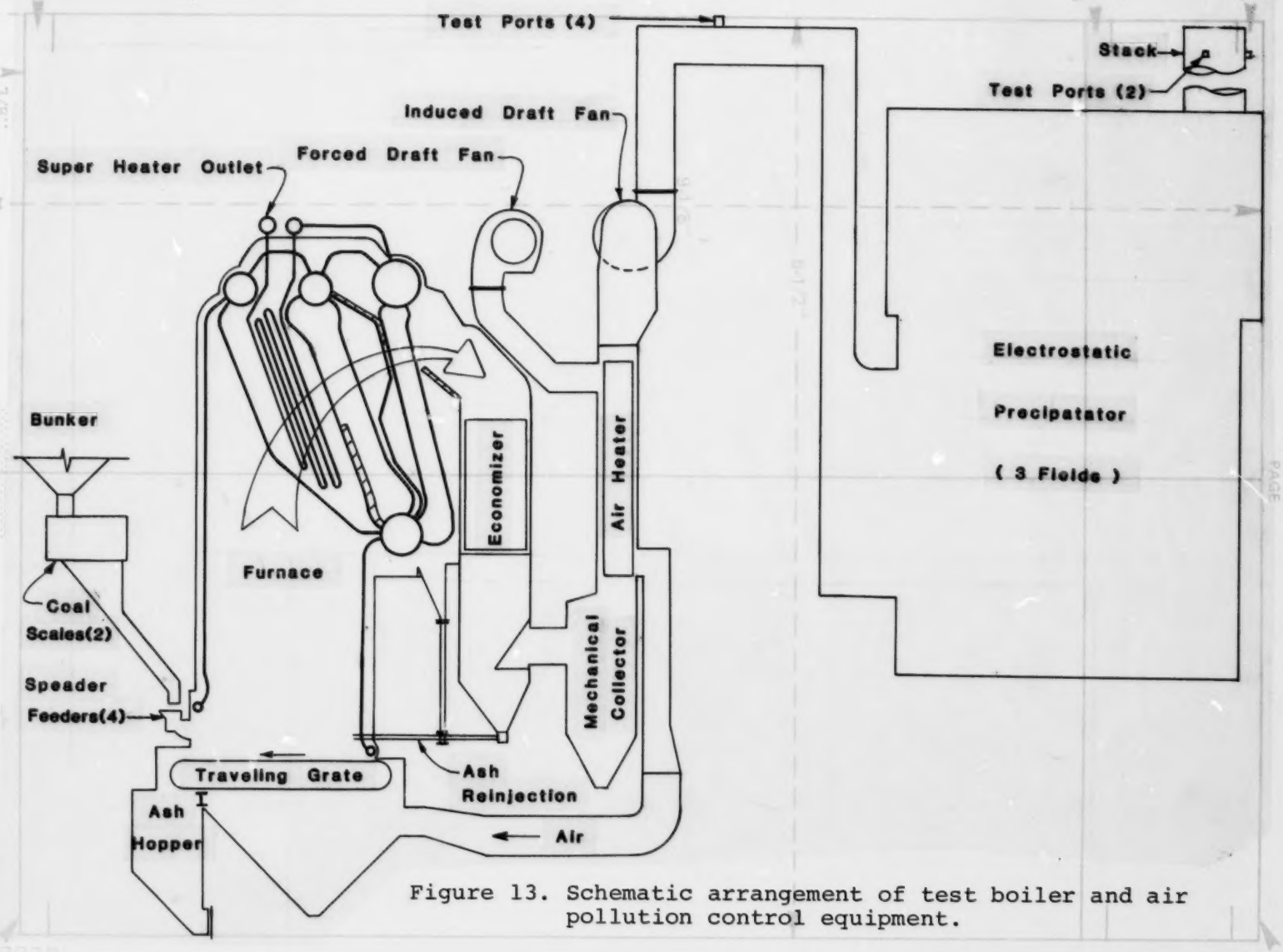

Figure 13. Schematic arrangement of test boiler and air pollution control equipment.

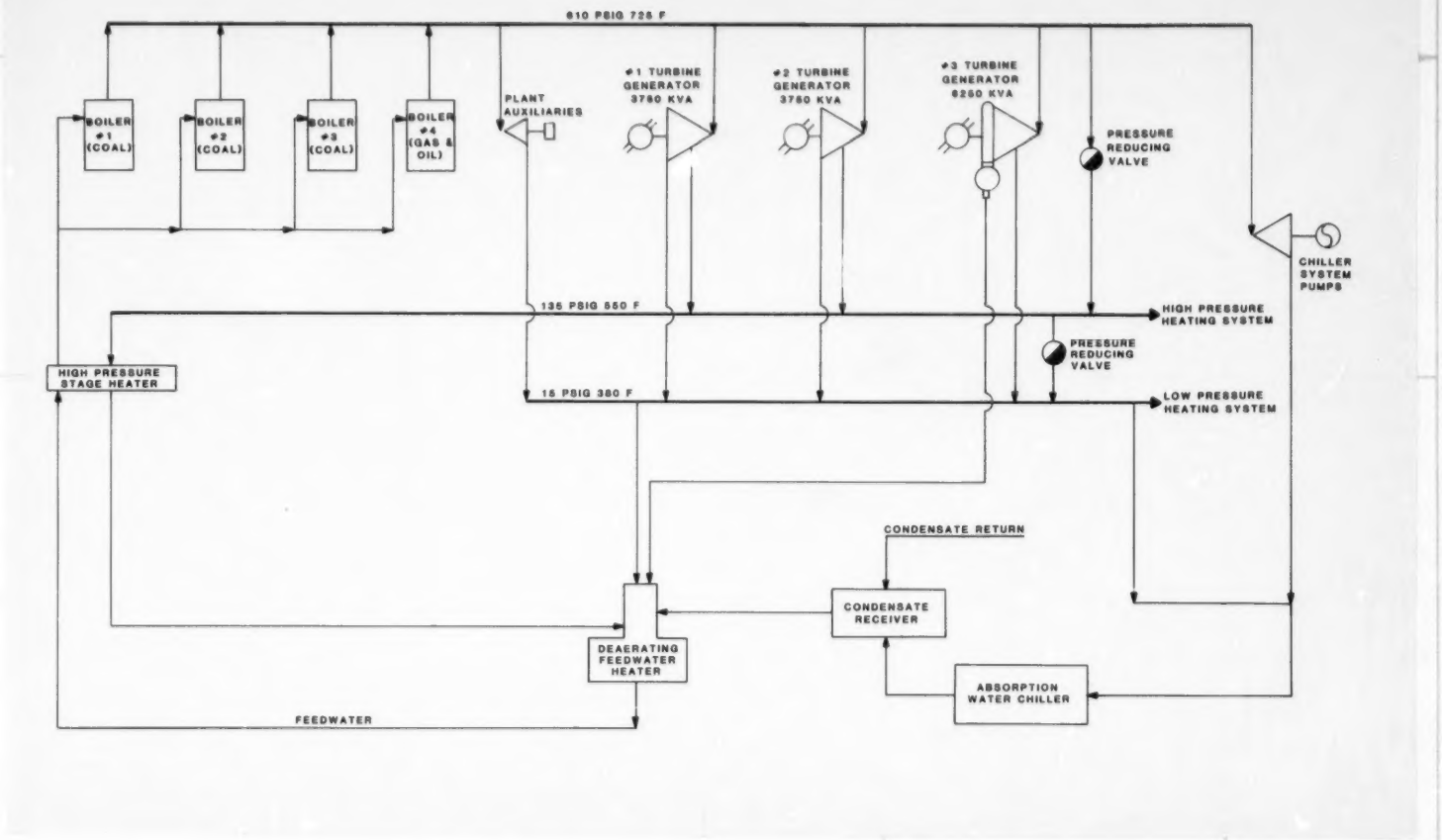

Figure 14. Schematic arrangement of Milwaukee County Institutions' Co-generation Power Plant.

the Institutions' existing boilers is 0.15 pounds of particulate emission per million Btu's of heat input. (New source particulate emission standards established by the US Environmental Protection Agency would, if applicable, limit particulate emissions from these boilers to 0.10 pounds of particulate per million Btu's of heat input.) Previously made performance acceptance tests on the electrostatic precipitators indicate that actual emission rates were below 0.10 pounds of particulate per million Btu's of heat input at rated load.

BOILER OPERATION

Feed to Boiler

In operation, the coal/d-RDF mixture fed reasonably well through the conical chutes and the spreader stoker feeders. On occasion however, hangups did occur and manual rodding was required. These problems occurred when higher percentages of d-RDF were experienced. By the time fuel reached the boilers, very little of the refuse could be characterized as "cubed". Throughout the fuel handling system, there was progressive breakdown of the densified material.

Tendency to Clinker

Once in the furnace, the d-RDF burned well. The coal/d-RDF mixture did tend to clinker more frequently than coal alone. This entailed constant operator attention.

Unburned d-RDF

Some refuse, still in cube form, was not entirely burned as it dropped into the ash pit. In examples examined, a core of carbon remained in the cubes roughly the diameter of a nickel. There was no evidence of unvolatilized material. Considering that the combustible portion of refuse is something like 85% volatile, the unburned combustible loss as fixed carbon in a few cubes does not represent a major heat loss.

Particulate Carry-Over

To the eye, carry-over of particulate from the furnace into the convection bank did not appear to be significantly greater when firing the coal/d-RDF mixture than when firing coal alone. "Sparklers" were rarely evident in the sight glasses for the fly ash reinjection system. "Sparklers" are quite evident in spreader stoker fired boilers where fluff RDF is air swept into the boiler furnace.

Ash Handling

With the rather small percentage of energy input in the form of refuse, problems were not encountered in the ash handling system.

Load Carrying Ability

Steaming ability was limited when d-RDF was fired along with coal. The plant operators had devised a system to increase the feeder stroke in order to maximize steam generation rates with poor quality fuel. Even with maximum extended stroke, the test boiler was not able to achieve steam generation rates that had been easily attained when firing coal alone. This was due to the volumetric limitations of the spreader feeder equipment when firing the less dense coal/d-RDF mixture.

"Housekeeping" in the Power Plant

When d-RDF fuel was bunkered with coal, the refuse material could be handled without incurring housekeeping problems in the boiler plant. Some minor odor problems were reported by operating personnel.

SECTION 6

TEST PROGRAM

A comprehensive performance test program was developed to establish the impact of d-RDF on boiler performance, stack emissions and the leachate potential of the ash residues.

TWO PHASE PROGRAM

The test program was accomplished in two phases. Baseline data when firing coal alone were established on May 19 and 20, 1981. A mixture of coal and d-RDF was fired continuously from June 9th through June 17th. A comprehensive performance test program for the coal/d-RDF mixture was undertaken on June 16th and 17th. A schematic depicting the parameters measured for coal and the coal/d-RDF mixture is shown on Figure 15.

The test procedures described below are for the June test where coal is fired along with the d-RDF. The same procedures had been followed in the May test except, of course, d-RDF was not involved.

Fuel Quality

Grab samples were taken at each of the two weigh scales at half hour intervals, composited, and hand sorted to determine the percentage of coal and d-RDF by weight.

For each stack test run, representative samples were gathered for both coal and d-RDF. These samples were analyzed by Commercial Testing and Engineering Co. for:

- proximate analysis
- ultimate analysis
- heating value
- trace metals
- sieve analysis (coal only)
- ash softening temperature

Table 5 is a fuel comparison tabulation for the May coal test and the June coal/d-RDF mixture test. Each of the analyses for the coals and the d-RDF are tabulated. Coals analyzed during

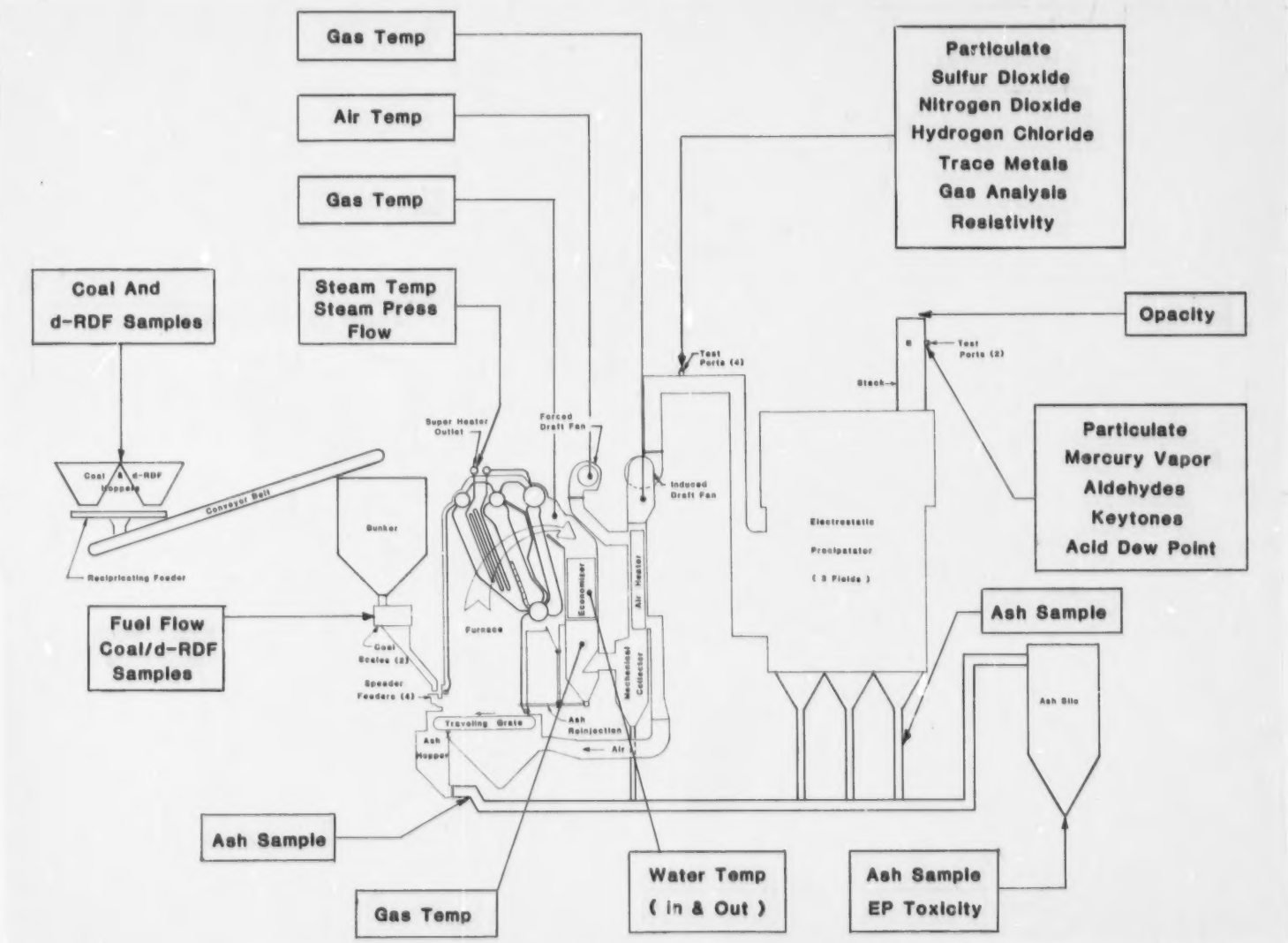

Figure 15. Schematic of test program

TABLE 5

FUEL COMPARISON

Fuel	COAL			COAL			d-RDF			MIXTURE			
Date	5/19	5/20		6/16	6/16	6/17	6/16	6/16	6/17	6/16	6/16	6/17	
Stack Test Run	1 & 2	3	Avg.	1	2	3	1	2	3	1	2	3	Avg.
Proximate Analysis													
Moisture, %	6.19	5.33	5.90	5.84	5.67	3.85	19.85	18.80	20.81	8.07	8.61	8.24	8.31
Ash, %	8.54	13.77	10.28	8.36	9.96	10.45	17.71	19.58	17.07	9.85	12.12	12.16	11.38
Volatile, %	36.64	34.30	35.86	36.39	36.12	36.44	60.10	-*	57.23	40.16	41.06	41.83	41.02
Fixed Carbon, %	48.63	46.60	47.96	49.41	48.25	49.26	2.34	-*	4.89	41.92	38.21	37.77	39.29
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Heating Value, Btu/lb	12661	12040	12454	12709	12511	12543	6139	5781	5669	11150	11000	10760	10970
Sulfur, %	2.04	2.14	2.07	2.04	2.41	2.32	0.22	0.18	0.25	1.75	1.91	1.72	1.79
Sizing													
>1-1/2", %	11.2	0		12.9	0	9.5	-	-	-	-	-	-	-
1-1/2"to 1/4", %	56.0	79.6		51.1	68.4	66.2	-	-	-	-	-	-	-
<1/4", %	32.8	20.4		36.0	31.6	24.3	-	-	-	-	-	-	-
Ash Softening Temp.													
(H=W) Reducing, F	2480	2470		2440	2520	2400	2210	2150	2280	-	-	-	-
Trace Metals													
Cadmium mg/kg	2.0	2.0		2.0	2.0	2.0	12.0	12.0	11.0	3.6	4.2	4.3	4.0
Beryllium mg/kg	0.8	1.9		2.9	3.3	3.3	2.0	2.0	2.0	2.8	3.0	3.0	2.9
Lead mg/kg	160.0	142.0		80.0	77.0	72.0	1540.0	1250.0	1900.0	312.1	339.8	545.5	399.1
Mercury mg/kg	0.1	0.1		0.3	0.2	0.2	2.0	2.0	2.5	0.6	0.6	0.8	0.7
Zinc mg/kg	320.0	320.0		224.0	254.0	325.0	2400.0	2250.0	2300.0	570.0	701.1	836.5	702.5
Portion of Fuel Input													
By Weight, %	100	100		84.1	77.6	74.1	15.9	22.4	25.9	-	-	-	21.4
By heating value, %	100	100		91.3	88.2	86.3	8.7	11.8	13.7	-	-	-	11.4 (d-RDF)

* Questionable Laboratory Data Reported.

the May tests are averaged. The coal and d-RDF for each of the runs during the June mixture are averaged for each of the stack test runs and the three runs are also averaged.

Table 6 is a tabulation of the ultimate fuel analyses for the May coal and June coal/d-RDF mixture stack test runs. Columns of averaged data for each of the test periods are displayed.

Ash Quality

For each of the stack test runs, representative samples were taken for:

- bottom ash
- precipitator catch
- combined ash

These samples were analyzed by Commercial Testing & Engineering Co. for:

- percent combustible
- heating value

Bottom ash samples were taken at the grate discharge during each of the stack test runs as tabulated in Table 7.

Precipitator catch samples were taken during each of the stack test runs as tabulated in Table 7.

It was not practical to obtain a sample of the material collected in the mechanical collector. It is known that this material contains a large percentage of unburned combustibles. A combined ash sample was taken for each of the test runs from the ash silo as tabulated in Table 7. Bottom ash, precipitator catch and material from the mechanical collector is all transported to the ash silo. Combined ash samples were taken from the ash silo as the silo was unloaded. These samples were also tested for EP Toxicity.

Boiler Performance

At 15 minute intervals during the test runs, boiler performance readings were taken for:

- steam flow and steam temperature
- water temperatures
- gas temperatures
- air temperatures
- steam pressure

TABLE 6

COMPARISON OF FUEL ULTIMATE ANALYSES

Fuel	COAL			COAL/d-ROP MIXTURE			
Date	5/19	5/20	Avg.	6/16	6/16	6/17	Avg.
Stack Test Run	1 & 2	3		1	2	3	
Ultimate Analysis							
Moisture, %	6.19	5.33	5.90	8.07	8.61	8.24	8.31
Carbon, %	70.18	66.91	69.09	64.41	61.24	60.42	62.02
Hydrogen, %	4.76	4.53	4.68	4.88	4.59	4.78	4.75
Nitrogen, %	1.14	1.09	1.12	1.03	1.07	1.08	0.99
Chlorine, %	0.19	0.17	0.18	0.24	0.27	0.21	0.24
Sulfur, %	2.04	2.14	2.07	1.75	1.91	1.72	1.79
Ash, %	8.54	13.77	10.28	9.85	12.12	12.16	11.38
Oxygen, %	6.96	6.06	6.68	9.77	10.19	11.59	10.52

TABLE 7

ASH AND UNBURNED COMBUSTIBLE

BOTTOM ASH

Fuel	COAL			COAL/d-RDF MIXTURE			
Date	5/19/81	5/20/81	Avg.	6/16/81	6/16/81	6/17/81	Avg.
Run	1 & 2	3		1	2	3	
Combustible, %	1.8	3.0	2.2	5.5	1.1	1.8	2.8
Heating Value, Btu/lb	167	332	222	718*	247	288	275 ♦

PRECIPITATOR CATCH

Fuel	COAL			COAL/d-RDF MIXTURE			
Date	5/19/81	5/20/81	Avg.	6/16/81	6/16/81	6/17/81	Avg.
Run	1 & 2	3		1	2	3	
Combustible, %	28.1	28.0	28.1	30.9	29.4	29.4	29.9

COMBINED ASH

Fuel	COAL			COAL/d-RDF MIXTURE			
Date	5/19-20/81			6/16/81	6/16/81	6/17/81	Avg.
Run	1, 2 & 3			1	2	3	
Combustible, %	14.40			14.2	16.8	8.7	13.2
Heating Value, Btu/lb	1676			1700	1937	873*	1700 ♦

* Questionable Data

♦ Used in Efficiency Calculation

In addition, integrator readings were taken for steam flow at the start and finish of each stack test run. Fuel flow was determined by recording the automatic dump reading at each scale for the duration of each run.

Emissions Testing

Comprehensive samples and data were taken at the precipitator inlet and the stack outlet to ascertain precipitator performance and stack emissions.

Precipitator inlet measurements were made for:

- particulate loadings (quantity and size distribution)
- sulfur dioxide
- nitrogen dioxide
- hydrogen chloride

Emission measurements were made at the stack outlet for:

- particulate loadings (quantity and size distribution)
- mercury vapor
- aldehydes
- ketones
- acid dew point
- opacity

Particulate collected at the precipitator inlet was analyzed for percent combustibles, resistivity and breakdown voltage. Particulate collected at the stack outlet was analyzed for:

- lead
- cadmium
- zinc
- mercury
- beryllium
- percent combustibles

The following techniques were used for analyses:

- particulate quantity - EPA Method 5
- particulate - size distribution - determined by cascade impactor (except for the May inlet runs where particles were collected isokinetically and analyzed for size by an electronic sizing device)
- sulfur dioxide - EPA Method 8
- nitrogen dioxide - EPA Method 7
- opacity - EPA Method 9

- mercury vapor - modified Method 101 of CFR-40 Parts 53-80
- aldehydes and ketones - gas samples were drawn through a charcoal filled tube and the absorbed organic gases were analyzed for aldehyde and ketone by gas chromatography
- acid dew point - determined by condensation of the sulfur dioxide in the flue gas following the method of E.S. Lisle and J.D. Sensenbaugh as published in Combustion, Vol. 36, No. 7, p. 12, January, 1965
- trace metals - determined by atomic absorption method
- resistivity and breakdown voltage - ASME PTC 28
- EP Toxicity - EPA Part 261, Appendix II

Mode of Operation During Test Program

At all times during the test program two coal fired boilers were maintained in operation. The test boiler, Unit #3, was to be held at constant load while the second boiler, Unit #2, automatically adjusted for varying load requirements of the Institutions' co-generation system. (During normal plant operation, two or more boilers are kept on the line, in parallel, automatically adjusting for system load variations).

Coal Used During Tests--

The coal fired during both the May and June tests was produced by the Glacia Mining Company of Strattonville, Pennsylvania as a blend of coals from the Kittaning and Clarion mines, both of which are part of the Pittsburgh Seam. The coal blend can be ranked as Class II Group 3 "high volatile A bituminous" by ASTM D-388.

May Tests--

For the May tests on coal alone, steam flow was held between 80,000 to 85,000 pounds per hour, the normal boiler operating range. Figures 16 and 17 are the steam flow charts for May 19 and 20. This presented little difficulty as the boiler was rated for a continuous load of 110,000 pounds per hour and a maximum load of 125,000 pounds per hour.

June Tests--

The difficulty in attaining and maintaining boiler load when burning d-RDF is clearly demonstrated when Figures 16 and 17 are compared with Figures 18 and 19 which are tracings of steam charts for the stack test runs when firing a mixture of coal and d-RDF in June.

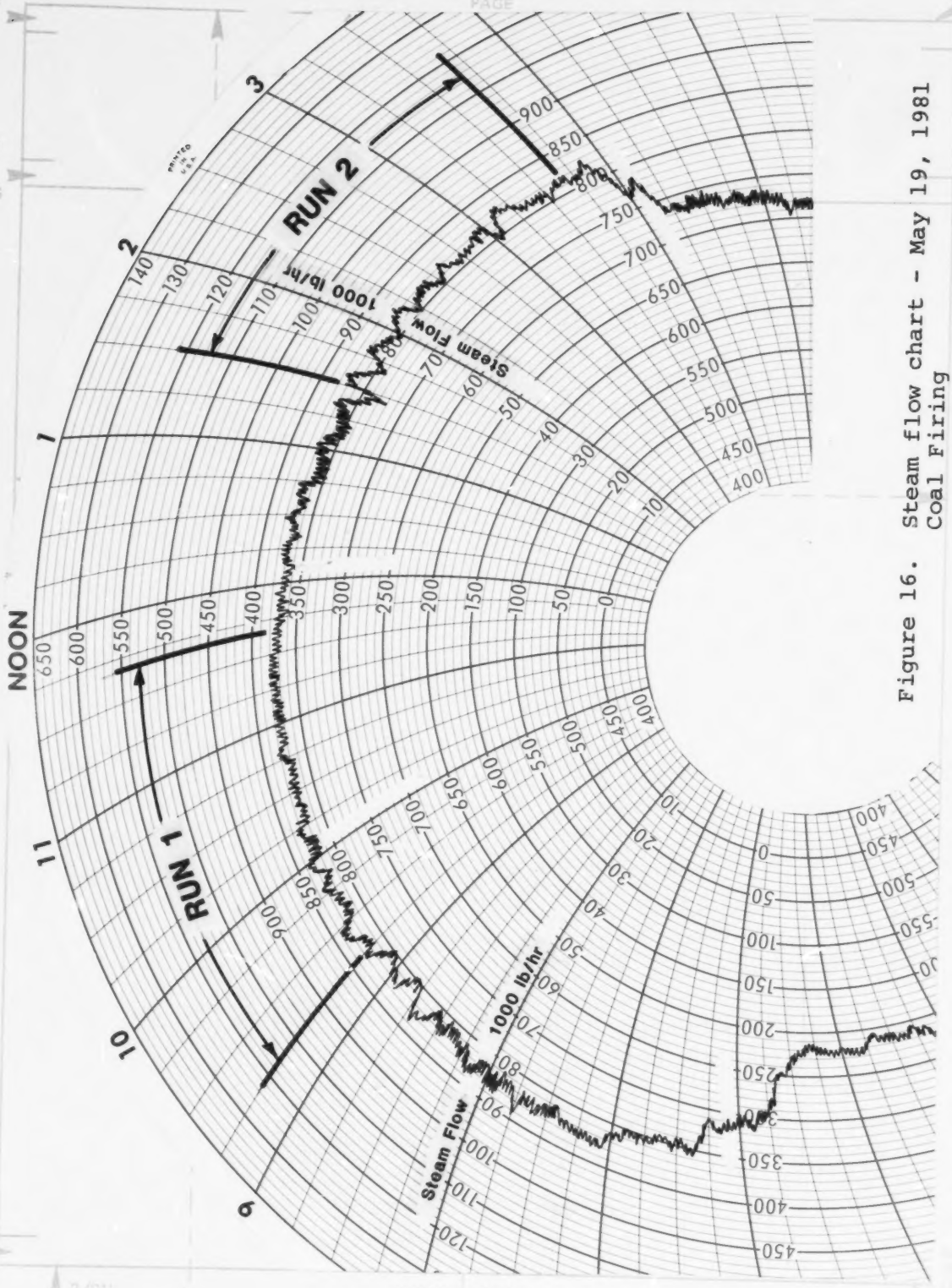

Figure 16. Steam flow chart - May 19, 1981
Coal Firing

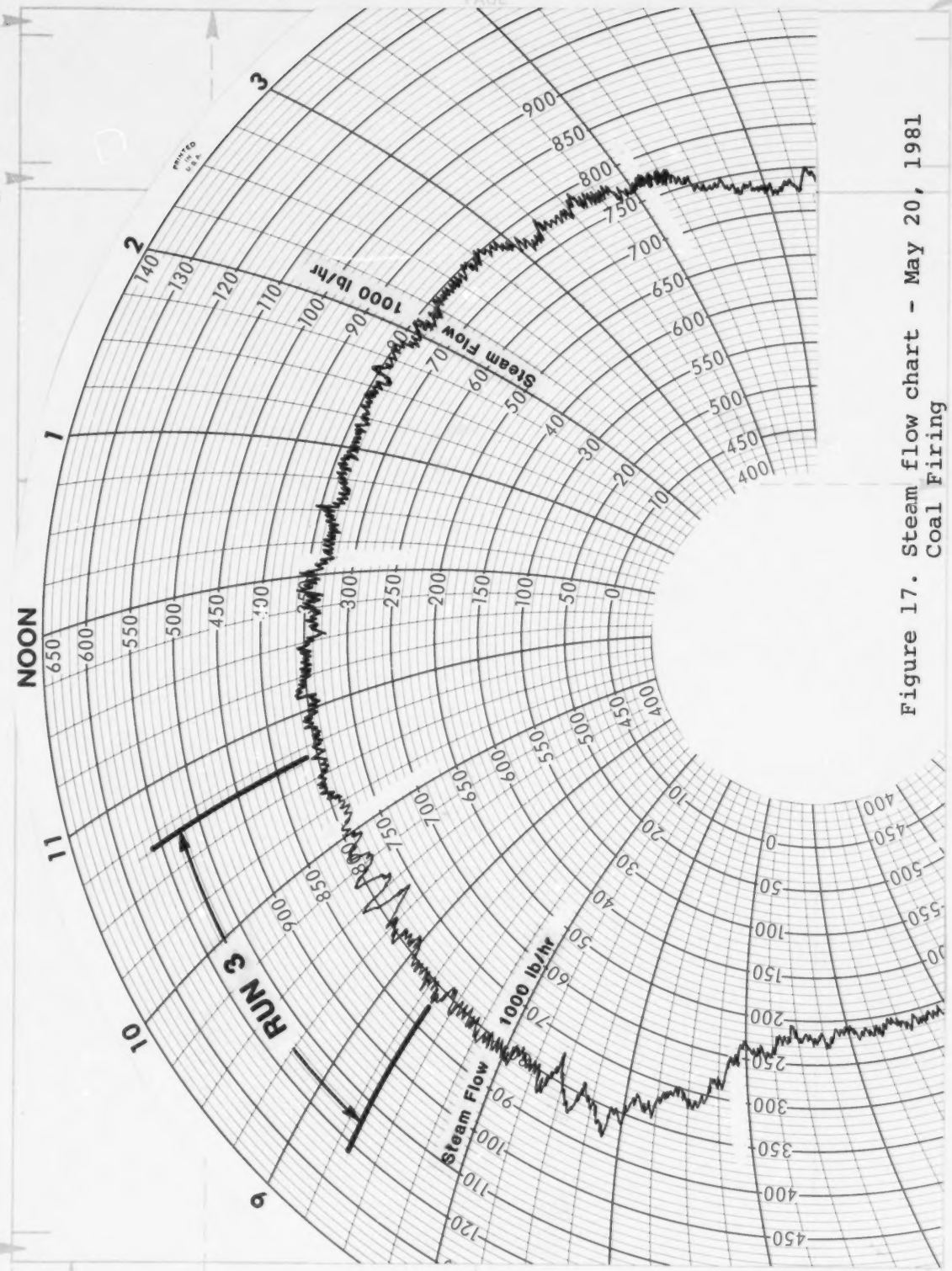

Figure 17. Steam flow chart - May 20, 1981
Coal Firing

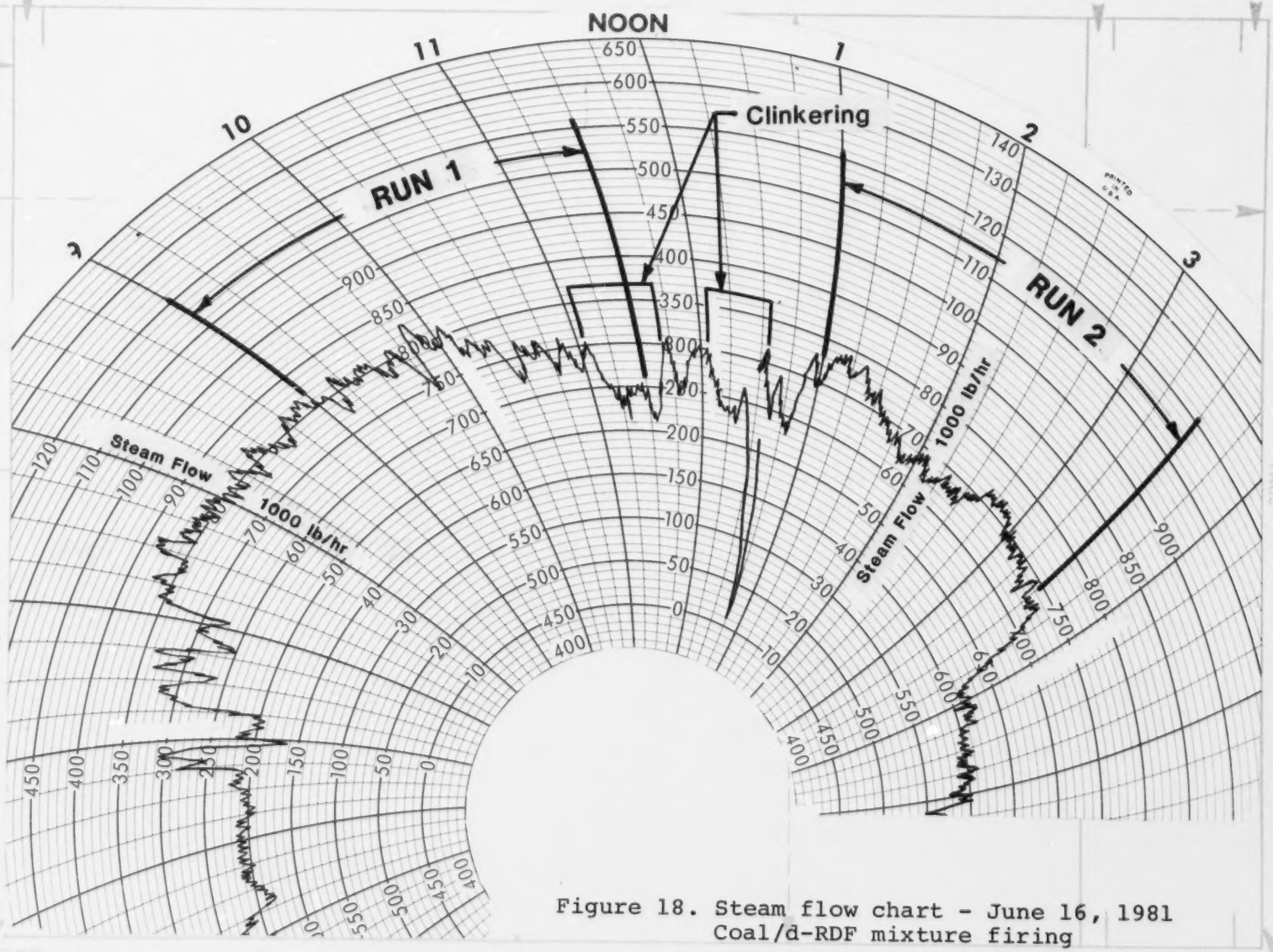

Figure 18. Steam flow chart - June 16, 1981
Coal/d-RDF mixture firing

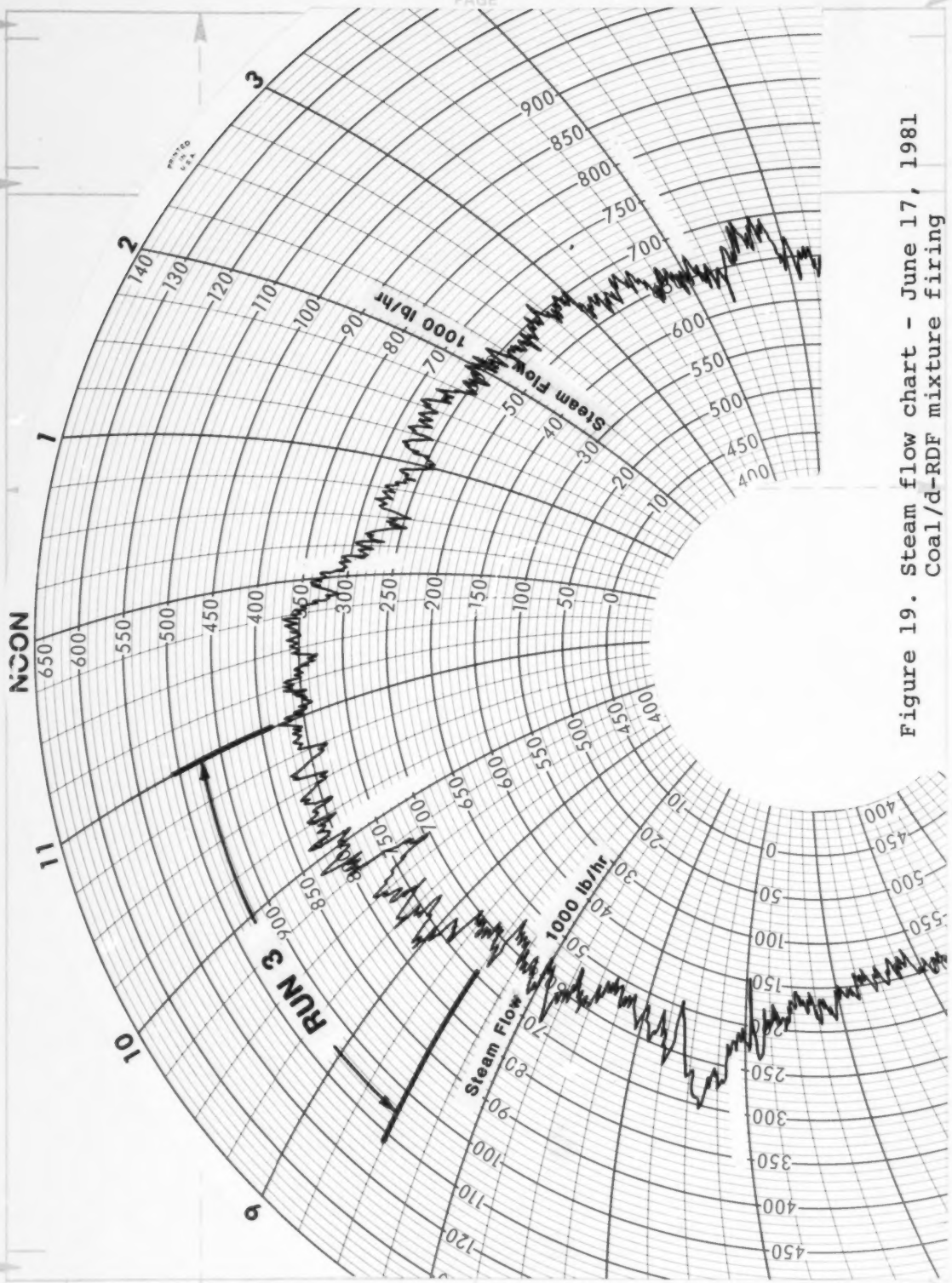

Figure 19. Steam flow chart - June 17, 1981
Coal/d-RDF mixture firing

A reasonably constant load of 40-50,000 pounds per hour was maintained throughout the night. In preparation for the test program, load was raised to 80,000 pounds per hour which was comparable to the rating for the coal only firing in May. It should be noted here that because of extensive "rat-holing" in the bunker during the night, an undetermined quantity of coal was transferred from Bunker No. 1 into Bunker No. 3. It was this predominantly coal slug that was being fired during the early stages of stack test Run 1 on June 16. As the run progressed, it was apparent that a larger percentage of d-RDF appeared in the fuel mixture. Grate ash clinkering was experienced toward the end of the run.

A major clinker formed during the period between stack test Runs 1 and 2. This was cleared between 12:30 and 12:45 PM. During that time, steam flow dropped to below 20,000 pounds per hour.

Load recovered sufficiently by 1:00 PM to commence stack test Run 2. Steam flow was maintained fairly well throughout this run. Upon completion of the run, load was again dropped to 40-50,000 pounds per hour.

In the early morning hours of June 17, in preparation for stack test Run 3, an attempt was made to reach 70,000 pounds per hour of steam flow. This was achieved with great difficulty with all fuel feeding equipment running at full capacity. Towards the mid-point of stack test Run 3, a load of 80,000 pounds per hour was achieved and held throughout the remainder of the run. Based on the previous difficulty in obtaining 80,000 pounds per hour, it can be surmised that a coal rich mixture was experienced toward the end of stack test Run 3.

Difficulty with Fuel Mix--

All of the above illustrates the difficulty of achieving a uniform fuel mix. All of the fuel mixture bunkered for the test runs was mixed with the same feed rate of coal and d-RDF. Heating values of coal and d-RDF used in the fuel mixtures did not vary to a major degree from one run to another. The goal throughout all of the runs was to maintain 80,000 to 85,000 pounds of steam flow per hour.

Therefore, it must be concluded that the inability to achieve the desired boiler load and the inability to maintain a steady load was attributable to the variation in the fuel mixture, and the inability of the spreader feeders to fire adequate volumes of low density coal/d-RDF fuel mixtures.

This is not to suggest that d-RDF is not a suitable boiler fuel. But rather, it is to point out the inherent limitations of the Power Plant's coal handling and spreader feeder equipment to achieve and maintain desired boiler loads when firing a low

density coal/d-RDF mixture. It should be pointed out that the existing plant successfully carries rated boiler load when firing the coal of the rank used in these tests.

TEST RESULTS

Boiler Performance

Boiler performance for both the coal only and coal/d-RDF mixture runs are summarized in Table 8. Although it was possible to maintain the desired steam flow for all three stack test runs with coal only, it was not possible with coal/d-RDF test runs. It will be noted, however, that near comparable carbon dioxide levels were maintained in the flue gas for both types of fuel.

Efficiency Calculations

Using this data, plus fuel and ash data from Tables 5, 6, and 7, ASME Short Form boiler efficiency calculations were made for coal and coal/d-RDF mixture. Flue gas determinations were made at the inlet to the precipitator by the stack test team. Therefore, efficiency calculations were made based on temperatures and flue gas composition at the precipitator inlet rather than the air heater outlet. The temperature difference between the air heater outlet and the precipitator inlet is due, at least in part, to infiltration of air through the intervening breeching and induced draft fan. The effect of infiltration on efficiency should be comparable for both the May and June runs. Summaries and calculations are displayed on Figures 20, 21, 22 and 23.

Efficiencies Summary

Efficiencies and other pertinent data are tabulated in Table 9. The difference in heat loss efficiency between the May coal runs and the June coal/d-RDF mixture runs of 2.0 percent is largely due to the higher moisture and hydrogen content of the coal/d-RDF mixture. In addition, the somewhat lower carbon dioxide level in the flue gas (indication of a higher excess air level) tends to reduce the efficiency of the coal/d-RDF runs relative to the coal runs. The fact that the coal/d-RDF runs are at a lower steaming rate than the coal runs would also tend to have slight adverse effect on heat loss efficiency. The difference between the heat loss efficiency and output/input efficiency for both fuels is not readily apparent. In both cases output/input efficiency is higher than heat loss efficiency. Because temperature at the precipitator inlet was used, heat loss efficiency as calculated is artifically high. On the other hand, the allowance for "unmeasured losses" for heat loss efficiency calculations may not have been adequate to cover sensible heat losses in bottom ash and fly ash. Further the heat loss

TABLE 8

BOILER PERFORMANCE

Fuel	COAL				COAL/d-RDF MIXTURE			
Date	5/19/81	5/19/81	5/20/81		6/16/81	6/16/81	6/16/81	
Stack Test Run	1	2	3	Avg.	1	2	3	Avg.
d-RDF by Weight, %	0	0	0	0	15.9	22.4	25.9	21.4
Steam Flow, lb/hr	85,000	84,000	78,700	82,600	72,200	70,900	73,400	72,200
Fuel Fired, lb/hr	8,050	7,580	7,590	7,740	8,030	7,510	8,480	8,010
Drum Pressure, psig	620	620	620	620	620	615	620	620
Temperatures								
Gas								
Boiler Outlet, F	615	610	615	615	605	620	615	615
Economizer Outlet, F	455	450	455	455	455	460	460	460
Airheater Outlet, F	380	380	380	380	370	370	375	370
Precipitator Inlet, F	335	335	335	335	340	340	340	340
Air								
Airheater Inlet, F	110	110	110	110	115	115	110	115
Airheater, Outlet, F	225	220	230	225	230	230	230	230
Steam								
Superheater, Outlet, F	725	705	720	715	720	740	730	730
Water								
Economizer Inlet, F	350	350	350	350	360	360	360	360
Economizer Outlet, F	440	440	440	440	445	450	445	445
Gas Analysis (Dry)								
Precipitator Inlet								
CO_2	11.0	10.5	10.5	10.7	11.0	9.7	9.2	10.0
O_2	10.0	10.0	10.0	10.0	9.5	10.5	11.0	10.3
N_2	79.0	79.5	79.5	79.3	79.5	79.8	79.8	79.7

SUMMARY SHEET — ASME TEST FORM FOR ABBREVIATED EFFICIENCY TEST — PTC 4.1-a (1964)

COAL FIRING

AVERAGE CONDITIONS

THREE RUNS-MAY 19&20,1981

PRESSURES & TEMPERATURES

1	STEAM PRESSURE IN BOILER DRUM	psia	635
2	STEAM PRESSURE AT S. H. OUTLET	psia	625
3	STEAM PRESSURE AT R. H. INLET	psia	—
4	STEAM PRESSURE AT R. H. OUTLET	psia	—
5	STEAM TEMPERATURE AT S. H. OUTLET	F	715
6	STEAM TEMPERATURE AT R. H. INLET	F	—
7	STEAM TEMPERATURE AT R.H. OUTLET	F	—
8	WATER TEMP. ENTERING (ECON.)(BOILER)	F	350
9	STEAM QUALITY % MOISTURE OR P. P. M.		
10	AIR TEMP. AROUND BOILER (AMBIENT)	F	80
11	TEMP. AIR FOR COMBUSTION (This is Reference Temperature)	F	110
12	TEMPERATURE OF FUEL	F	80
13	GAS TEMP. ENTERING PRECIPITATOR	F	335
14	GAS TEMP. ENTERING AH (If conditions to be corrected to guarantee)	F	

UNIT QUANTITIES

15	ENTHALPY OF SAT. LIQUID (TOTAL HEAT)	Btu/lb	
16	ENTHALPY OF (SATURATED) (SUPERHEATED) STM.	Btu/lb	1359
17	ENTHALPY OF SAT. FEED TO (BOILER) (ECON.)	Btu/lb	323
18	ENTHALPY OF REHEATED STEAM R.H. INLET	Btu/lb	—
19	ENTHALPY OF REHEATED STEAM R. H. OUTLET	Btu/lb	—
20	HEAT ABS. LB OF STEAM (ITEM 16 – ITEM 17)	Btu/lb	1036
21	HEAT ABS. LB R. H. STEAM (ITEM 19 – ITEM 18)	Btu/lb	—
22	DRY REFUSE (ASH PIT + FLY ASH) PER LB AS FIRED FUEL	lb/lb	0.12
23	Btu PER LB IN REFUSE (WEIGHTED AVERAGE)	Btu/lb	1676
24	CARBON BURNED PER LB AS FIRED FUEL	lb/lb	0.677
25	DRY GAS PER LB AS FIRED FUEL BURNED	lb/lb	15.94

HOURLY QUANTITIES

26	ACTUAL WATER EVAPORATED	lb/hr	82,600
27	REHEAT STEAM FLOW	lb/hr	—
28	RATE OF FUEL FIRING (AS FIRED wt)	lb/hr	7740
29	TOTAL HEAT INPUT (Item 28 × Item 41) / 1000	kB/hr	94,400
30	HEAT OUTPUT IN BLOW-DOWN WATER	kB/hr	—
31	TOTAL HEAT OUTPUT (Item 26×(Item 20)+(Item 27×(Item 23)+Item 30 / 1000	kB/hr	85,600

FLUE GAS ANAL. (BOILER)(ECON) (AIR HTR) OUTLET

32	CO_2	% VOL	10.7
33	O_2	% VOL	10.0
34	CO	% VOL	—
35	N_2 (BY DIFFERENCE)	% VOL	79.3
36	EXCESS AIR	%	88.5

FUEL DATA

	AS FIRED PROX. ANALYSIS	% wt		OIL	
37	MOISTURE	5.90	51	FLASH POINT F°	
38	VOL MATTER	35.86	52	Sp. Gravity Deg. API°	
39	FIXED CARBON	47.96	53	VISCOSITY AT SSU° BURNER SSF	
40	ASH	10.28	44	TOTAL HYDROGEN % wt	
	TOTAL	100.00	41	Btu per lb	
41	Btu per lb AS FIRED	12454			
42	ASH SOFT TEMP.° ASTM METHOD			GAS	% VOL
	AS FIRED ULTIMATE ANALYSIS		54	CO	
43	CARBON	69.09	55	CH_4 METHANE	
44	HYDROGEN	4.68	56	C_2H_2 ACETYLENE	
45	OXYGEN	6.68	57	C_2H_4 ETHYLENE	
46	NITROGEN + Cl	1.30	58	C_2H_6 ETHANE	
47	SULPHUR	2.07	59	H_2S	
40	ASH	10.28	60	CO_2	
37	MOISTURE	5.90	61	H_2 HYDROGEN	
	TOTAL	100.00		TOTAL	
	COAL PULVERIZATION			TOTAL HYDROGEN % wt	
48	GRINDABILITY INDEX*		62	DENSITY 68 F ATM. PRESS.	
49	FINENESS % THRU 50 M*		63	Btu PER CU FT	
50	FINENESS % THRU 200 M*		41	Btu PER LB	
64	INPUT-OUTPUT EFFICIENCY OF UNIT %	ITEM 31 × 100 / ITEM 29		88.9	

	HEAT LOSS EFFICIENCY	Btu/lb A. F. FUEL	% of A. F. FUEL
65	HEAT LOSS DUE TO DRY GAS	861	6.9
66	HEAT LOSS DUE TO MOISTURE IN FUEL	69	0.6
67	HEAT LOSS DUE TO H_2O FROM COMB. OF H_2	491	4.0
68	HEAT LOSS DUE TO COMBUST. IN REFUSE	201	1.6
69	HEAT LOSS DUE TO RADIATION	100	0.8
70	UNMEASURED LOSSES	125	1.0
71	TOTAL		14.9
72	EFFICIENCY = (100 – Item 71)		85.1

* Not Required for Efficiency Testing

Figure 20. Coal Firing - Average Conditions - Three Runs - Summary Sheet.

PTC 4.1-b (1964)

CALCULATION SHEET — ASME TEST FORM FOR ABBREVIATED EFFICIENCY TEST — Revised September, 1965

COAL FIRING

30 HEAT OUTPUT IN BOILER BLOW-DOWN WATER = LB OF WATER BLOW-DOWN PER HR × [(ITEM 15 − ITEM 17) / 1000] = ... LB/hr

24 *If impractical to weigh refuse, this item can be estimated as follows*

DRY REFUSE PER LB OF AS FIRED FUEL = (% ASH IN AS FIRED COAL) / (100 − % COMB. IN REFUSE SAMPLE) = 10.28 / (100 − 14.40) = 0.12

CARBON BURNED PER LB AS FIRED FUEL = ITEM 43 / 100 − [(ITEM 22 × ITEM 23) / 14,500] = 69.09 / 100 − [(0.12 × 1676) / 14,500] = 0.677

25 DRY GAS PER LB AS FIRED FUEL BURNED = [11 CO_2 + 8 O_2 + 7 (H_2 + CO)] / [3 (CO_2 + CO)] × (LB CARBON BURNED PER LB AS FIRED FUEL + (3/8) S)

= 11 × ITEM 22 / [3 × (ITEM 32 + ITEM 34)] + 8 × ITEM 23 / [3 × (ITEM 32 + ITEM 34)] + 7 × (ITEM 35 + ITEM 36) / [3 × (ITEM 32 + ITEM 34)] × [ITEM 24 + ITEM 47 / 267]

= 11 × 10.9 / [3 × (10.7 + .0)] + 8 × 10.0 / [3 × (10.7 + .0)] + 7 × (79.3 + 0) / [3 × (10.7 + .0)] × [0.677 + 2.07 / 267] = 15.94

36 EXCESS AIR = 100 × [O_2 − CO/2] / [.2682 N_2 − (O_2 − CO/2)] = 100 × [10.0 − 0/2] / [.2682 (79.3) − (10.0 − 0/2)] = 88.5

	HEAT LOSS EFFICIENCY	Btu/lb AS FIRED FUEL	LOSS / HHV × 100 =	LOSS %
65	HEAT LOSS DUE TO DRY GAS = LB DRY GAS PER LB AS FIRED FUEL × C_p × (t_{vg} − t_{air}) = ITEM 25 × 0.24 × (ITEM 13 − ITEM 11) = 15.94 × 0.24 × (335 − 86) =	861	65/41 × 100 =	6.9
66	HEAT LOSS DUE TO MOISTURE IN FUEL = LB H_2O PER LB AS FIRED FUEL × [(ENTHALPY OF VAPOR AT 1 PSIA & T GAS LVG) − (ENTHALPY OF LIQUID AT T AIR)] = 5.90/100 × (1212 − 48) = 69	69	66/41 × 100 =	0.6
67	HEAT LOSS DUE TO H_2O FROM COMB. OF H_2 = 9 H_2 × [(ENTHALPY OF VAPOR AT 1 PSIA & T GAS LVG) − (ENTHALPY OF LIQUID AT T AIR)] = 9 × 4.68/100 × (1212 − 48) = 491	491	67/41 × 100 =	4.0
68	HEAT LOSS DUE TO COMBUSTIBLE IN REFUSE = ITEM 22 × ITEM 23 = 0.12 × 1676 = 201	201	68/41 × 100 =	1.6
69	HEAT LOSS DUE TO RADIATION	100	69/41 × 100 =	0.8
70	UNMEASURED LOSSES	125	70/41 × 100 =	1.0
71	TOTAL	1847	.....	14.9
72	EFFICIENCY = (100 − ITEM 71)	.....	.....	85.1

Figure 21. Coal Firing - Calculation Sheet.

SUMMARY SHEET — ASME TEST FORM FOR ABBREVIATED EFFICIENCY TEST — PTC 4.1-a(1964)

COAL/d-RDF MIXTURE FIRING

AVERAGE CONDITIONS

THREE RUNS-JUNE 16&17, 1981

PRESSURES & TEMPERATURES

1	STEAM PRESSURE IN BOILER DRUM	psia	635
2	STEAM PRESSURE AT S. H. OUTLET	psia	625
3	STEAM PRESSURE AT R. H. INLET	psia	—
4	STEAM PRESSURE AT R. H. OUTLET	psia	—
5	STEAM TEMPERATURE AT S. H. OUTLET	F	730
6	STEAM TEMPERATURE AT R. H. INLET	F	—
7	STEAM TEMPERATURE AT R. H. OUTLET	F	—
8	WATER TEMP. ENTERING (ECON.) (BOILER)	F	360
9	STEAM QUALITY % MOISTURE OR P. P. M.		
10	AIR TEMP. AROUND BOILER (AMBIENT)	F	80
11	TEMP. AIR FOR COMBUSTION (This is Reference Temperature)	F	115
12	TEMPERATURE OF FUEL	F	80
13	GAS TEMP. ENTERING PRECIPITATOR	F	340
14	GAS TEMP. ENTERING AH (If conditions to be corrected to guarantee)	F	

UNIT QUANTITIES

15	ENTHALPY OF SAT. LIQUID (TOTAL HEAT)	Btu/lb	
16	ENTHALPY OF (SATURATED) (SUPERHEATED) STM	Btu/lb	1368
17	ENTHALPY OF SAT. FEED TO (BOILER) (ECON.)	Btu/lb	333
18	ENTHALPY OF REHEATED STEAM R. H. INLET	Btu/lb	—
19	ENTHALPY OF REHEATED STEAM R. H. OUTLET	Btu/lb	—
20	HEAT ABS. LB OF STEAM (ITEM 16 – ITEM 17)	Btu lb	1035
21	HEAT ABS. LB R. H. STEAM (ITEM 19 – ITEM 18)	Btu/lb	—
22	DRY REFUSE (ASH PIT + FLY ASH) PER LB AS FIRED FUEL	lb/lb	0.13
23	Btu PER LB IN REFUSE (WEIGHTED AVERAGE)	Btu/lb	1700
24	CARBON BURNED PER LB AS FIRED FUEL	lb/lb	0.605
25	DRY GAS PER LB AS FIRED FUEL BURNED	lb/lb	14.98

HOURLY QUANTITIES

26	ACTUAL WATER EVAPORATED	lb/hr	72,200
27	REHEAT STEAM FLOW	lb/hr	—
28	RATE OF FUEL FIRING (AS FIRED wt)	lb/hr	8010
29	TOTAL HEAT INPUT (Item 28 × Item 41) / 1000	kB/hr	87,900
30	HEAT OUTPUT IN BLOW-DOWN WATER	kB/hr	
31	TOTAL HEAT OUTPUT (Item 26 × Item 20) + (Item 27 × Item 21) + Item 30 / 1000	kB/hr	74,700

FLUE GAS ANAL. (BOILER) (ECON) (AIR HTR) OUTLET

32	CO_2	% VOL	10.0
33	O_2	% VOL	10.3
34	CO	% VOL	
35	N_2 BY DIFFERENCE	% VOL	79.7
36	EXCESS AIR	%	92.8

FUEL DATA

37	AS FIRED PROX. ANALYSIS: MOISTURE	% wt	8.31	51	OIL: FLASH POINT F°		
38	VOL MATTER		41.02	52	Sp. Gravity Deg. API°		
39	FIXED CARBON		39.29	53	VISCOSITY AT SSU° BURNER SSF		
40	ASH		11.38	44	TOTAL HYDROGEN % wt		
	TOTAL		100.00	41	Btu per lb		
41	Btu per lb AS FIRED		10970				
42	ASH SOFT TEMP.* ASTM METHOD				GAS		% VOL
	AS FIRED ULTIMATE ANALYSIS			54	CO		
43	CARBON		62.02	55	CH_4 METHANE		
44	HYDROGEN		4.75	56	C_2H_2 ACETYLENE		
45	OXYGEN		10.52	57	C_2H_4 ETHYLENE		
46	NITROGEN + Cl		1.23	58	C_2H_6 ETHANE		
47	SULPHUR		1.79	59	H_2S		
48	ASH		11.38	60	CO_2		
37	MOISTURE		8.31	61	H_2 HYDROGEN		
	TOTAL		100.00		TOTAL		
	COAL PULVERIZATION				TOTAL HYDROGEN % wt		
48	GRINDABILITY INDEX*			62	DENSITY 68 F ATM. PRESS.		
49	FINENESS % THRU 50 M*			63	Btu PER CU FT		
50	FINENESS % THRU 200 M*			41	Btu PER LB		
64	INPUT-OUTPUT EFFICIENCY OF UNIT %		ITEM 31 × 100 / ITEM 29 = 85.1				

	HEAT LOSS EFFICIENCY	Btu/lb A. F. FUEL	% of A. F. FUEL
65	HEAT LOSS DUE TO DRY GAS	809	7.4
66	HEAT LOSS DUE TO MOISTURE IN FUEL	97	0.9
67	HEAT LOSS DUE TO H_2O FROM COMB OF H_2	499	4.6
68	HEAT LOSS DUE TO COMBUST. IN REFUSE	221	2.0
69	HEAT LOSS DUE TO RADIATION	100	0.9
70	UNMEASURED LOSSES	125	1.1
71	TOTAL		16.9
72	EFFICIENCY = (100 – Item 71)		83.1

* Not Required for Efficiency Testing

Figure 22. Coal/d-RDF Mixture Firing - Average Conditions - Three Runs - Summary Sheet.

PTC 4.1-b (1964)

CALCULATION SHEET — ASME TEST FORM FOR ABBREVIATED EFFICIENCY TEST — *Revised September, 1965*

COAL/d-RDF MIXTURE FIRING

38 HEAT OUTPUT IN BOILER BLOW-DOWN WATER = LB OF WATER BLOW-DOWN PER HR × [(ITEM 15 − ITEM 17) / 1000] = ... LB/hr

24 *If impractical to weigh refuse, this item can be estimated as follows*

DRY REFUSE PER LB OF AS FIRED FUEL = (% ASH IN AS FIRED COAL) / (100 − % COMB. IN REFUSE SAMPLE) = 11.38 / (100 − 13.2) = 0.13

CARBON BURNED PER LB AS FIRED FUEL = (ITEM 43)/100 − [(ITEM 22 × ITEM 23)/14,500] = 62.02/100 − [(0.13 × 1700)/14,500] = 0.605

25 DRY GAS PER LB AS FIRED FUEL BURNED = [11(CO₂ + ⅜SO₂ + 7(N₂ + CO)) / 3(CO₂ + CO)] × (LB CARBON BURNED PER LB AS FIRED FUEL + (3/8)S)

= [11 × (ITEM 32 = 10.0) + 8 × (ITEM 33 = 10.3) + 7(ITEM 35 = 79.7 + ITEM 34 = 0)] / [3 × (ITEM 32 = 10.0 + ITEM 34 = 0)] × [(ITEM 24 = 0.605 + ITEM 47 = 1.79)/267] = 14.98

36 EXCESS AIR = 100 × (O₂ − CO/2) / (.2682N₂ − (O₂ − CO/2)) = 100 × (10.3 − 0/2) / (.2682(79.7) − (10.3 − 0/2)) = 92.8

	HEAT LOSS EFFICIENCY	Btu/lb AS FIRED FUEL	LOSS / HHV × 100 =	LOSS %
65	HEAT LOSS DUE TO DRY GAS = LB DRY GAS PER LB AS FIRED FUEL × C_p × (t_{vg} − t_{air}) = ITEM 25 = 14.98 × 0.24 × (ITEM 13) − (ITEM 11) = 340 − 115 = 809	809	65/41 × 100 =	7.4
66	HEAT LOSS DUE TO MOISTURE IN FUEL = LB H_2O PER LB AS FIRED FUEL × [(ENTHALPY OF VAPOR AT 1 PSIA & T GAS LVG) − (ENTHALPY OF LIQUID AT T AIR)] = 8.31/100 × (1214 − 48) = 97	97	66/41 × 100 =	0.9
67	HEAT LOSS DUE TO H_2O FROM COMB. OF H_2 = 9H_2 × [(ENTHALPY OF VAPOR AT 1 PSIA & T GAS LVG) − (ENTHALPY OF LIQUID AT T AIR)] = 9 × 4.75/100 × (1214 − 48) = 499	499	67/41 × 100 =	4.6
68	HEAT LOSS DUE TO COMBUSTIBLE IN REFUSE = ITEM 22 = 0.13 × ITEM 23 = 1700 = ...	221	68/41 × 100 =	2.0
69	HEAT LOSS DUE TO RADIATION = ...	100	69/41 × 100 =	0.9
70	UNMEASURED LOSSES	125	70/41 × 100 =	1.1
71	TOTAL	.....	.....	16.9
72	EFFICIENCY = (100 − ITEM 71)	.....	.....	83.1

Figure 23. Coal/d-RDF Mixture Firing - Calculation Sheet.

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TABLE 9

EFFICIENCY COMPARISON

	COAL	COAL/d-RDF
Date	5/19-20/81	6/16-17/81
d-RDF, % weight	0	21.4
d-RDF, % heat input	0	11.4
CO_2, %	10.7	10.0
Gas Temp Entering Precipitator, F	335	340
Air Temp Entering Airheater, F	110	115
Output/input efficiency, %	88.9	85.1
Heat loss efficiency, %	85.1	83.1

PAGE NUMBER
EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 2367)
TYPING GUIDE SHEET

efficiencies did not include the heat lost in continuous blowdown from the steam drum. At an estimated blowdown of 2500 pounds per hour, this loss would be 0.4 percent.

The measured boiler efficiencies are considered very good for this type installation.

Particulate Emissions

Particulate emission data are summarized in Table 10.

Particulate Entering the Precipitator--

The quantity of particulate entering the precipitator when the coal/d-RDF mixture was fired was somewhat less than when coal was fired alone. This, in part, is due to reduced rate of boiler operations during the period when the coal/d-RDF mixture was fired. The significant variation in particulate size when the coal only test is compared to the coal/d-RDF mixture is not understood. It should be noted that the inlet particulate loadings are low if compared to many other installations due to the presence of the mechanical collector upstream from the precipitator.

Particulate Leaving the Precipitator--

The data indicates that a larger percentage of submicron particles leave the precipitator when firing a coal/d-RDF mixture. Particulate loadings are reported in pounds per million BTUs, (the normal measure for fossil fuel fired boilers) and in grains per standard cubic foot corrected to 12 percent carbon dioxide (the normal measure for incinerators). In addition, particulate loadings are reported in pounds per hour. In all measures the performance meets applicable emission standards.

Trace Metals--

As a whole, emission levels of various trace metals are low. There was an approximate ten fold increase in cadmium emissions when burning a coal/d-RDF mixture. Since the average weight of d-RDF in the fuel mixture was just over 20 percent, it would seem that more data, when burning higher d-RDF fuel mixtures, would be required to be able to draw any specific conclusions.

Opacity--

With regard to opacity, the test laboratory reported that in all cases visual emissions were less than five percent opacity. However, those participating in the test program observed that visual emissions from the boiler test Unit #3 when firing coal/d-RDF mixture were virtually undetectable, whereas visual emissions from the other plant operating boiler, Unit #2, which was fired by coal alone were light but nevertheless detectable. This same evaluation was also made in comparing the test boiler visible emissions for the two test series.

TABLE 10

PARTICULATE EMISSION COMPARISON

Fuel	COAL				COAL/d-RDF MIXTURE			
Stack Test Run	1	2	3	Avg.	1	2	3	Avg.
Date	5/19	5/19	5/20		6/16	6/16	6/17	
Steam Flow, lb/hr	85,000	84,000	78,000	82,600	72,200	70,400	73,400	72,200
d-RDF, % weight	0	0	0	0	15.9	22.4	25.9	21.4
Heat Input, 1000 Btu/hr				96,400				87,900
Carbon dioxide, %Vol (dry)	11.0	10.5	10.5	10.7	11.0	9.7	9.2	10.0
Precipitator Inlet								
Gas Flow, lb/hr	182,300	184,600	184,700	183,900	158,300	166,100	169,300	164,600
Gas Temp., F	335	337	334	335	340	340	340	340
Particulates								
Entering Precipitator								
Quantity, lb/hr	53.0	53.9	55.9	54.3	32.8	28.6	41.0	34.1
lb/10^6 Btu	0.52	0.56	0.61	0.56	0.35	0.35	0.45	0.38
Size >4.0μm, %	92.4	90.1	90.8	91.1	38.1	29.6	27.9	31.9
<0.8μm, %	1.5	1.3	2.0	1.6	38.4	47.4	49.5	45.1
Leaving Precipitator								
Quantity, lb/hr	9.2	8.3	8.5	8.7	5.5	5.0	5.9	5.5
lb/10^6 Btu	0.090	0.087	0.093	0.090	0.060	0.060	0.070	0.063
gr/scf (12%CO_2)	0.028	0.025	0.026	0.026	0.021	0.021	0.026	0.028
Size >4.0μm, %	72.4	68.8	75.9	72.4	46.4	30.8	51.0	42.7
<8.0μm, %	6.4	17.0	8.7	10.7	19.6	47.5*	17.8	28.3
Combustibles, %	2.1	2.3	2.4	2.3	0.6	0.5	0.8	0.6
Precipitator Efficiency, %	82.64	84.60	84.79	84.01	83.23	82.52	85.61	83.79
Acid Dew Point, F				295				300
Opacity				<5				<5
Trace Metals								
Lead, lb/hr	0.0052	0.0044	0.0044	0.0047	0.0069	0.0067	0.0096	0.0077
Cadmium, lb/hr	0.0007	0.0006	0.0006	0.0006	0.0061	0.0047	0.0067	0.0058
Zinc, lb/hr	0.0333	0.0336	0.0189	0.0286	0.0205	0.0224	0.0298	0.0242
Mercury, lb/hr	0.00002	0.00002	0.00001	0.00002	<0.00001	<0.00001	<0.00001	<0.00001
Beryllium, lb/hr	0.00004	0.00004	0.00004	0.00004	0.00004	0.00004	0.0001	0.00006

* Unreliable Datum

Acid Dew Point--

The acid dew point analysis indicated a figure of 295 F for coal fired runs and 300 F for the coal/d-RDF runs which is not considered to be a significant difference.

Gaseous Emissions

Gaseous emissions data are summarized in Table 11.

Sulfur Dioxide--

One would expect sulfur dioxide emissions to be reduced when firing a mixture of coal and low sulfur d-RDF when compared to firing coal alone. Average data from the test runs however indicates that sulfur dioxide emissions remain constant on a pounds per million BTU basis.

Nitrogen Dioxide--

The type of fuel fired appeared to have an insignificant impact on the level of nitrogen dioxide emitted.

Hydrogen Chloride--

As could be expected the level of hydrogen chloride emitted increased significantly when firing a coal/d-RDF mixture when compared to firing coal alone. However, it should be noted that the increase in hydrogen chloride emission is more than might be expected if chlorine levels in the two fuels from Table 6 are compared.

Electrical Characteristics

Inlet particulate was analyzed for resistivity and breakdown voltage. These data are tabulated in Table 12. There would appear to be no rationalization for the similarity in resistivity and wide variation in breakdown voltage between the two test series. These parameters merit further investigation before conclusions can be drawn.

EP Toxicity

Combined ash samples from the ash silo were analyzed for EP (Extraction Procedure) Toxicity. The results and EPA maximum allowable concentrations for characteristics of EP toxicity are tabulated in Table 13. The tests would suggest that concentrations decrease when d-RDF is fired with coal. There is no apparent reason why this should be so. More data will be required for a definitive answer. It does appear that EP Toxicity is likely to be less than EPA maximum concentration for boilers firing a coal/d-RDF mixture.

TABLE 11

GASEOUS EMISSION COMPARISON

Fuel	COAL				COAL/d-RDF			
Stack Test Run	1	2	3	Avg.	1	2	3	Avg.
Date	5/19	5/19	5/20		6/16	6/16	6/17	
Steam Flow, lb/hr	85,000	84,000	78,000	82,600	72,200	70,400	73,400	72,200
d-RDF, % weight	0	0	0	0	15.9	22.4	25.9	21.4
Heat Input, 1000 Btu/hr	-	-	-	96,400	-	-	-	87,900
Carbon Dioxide, %Vol (dry)	11.0	10.5	10.5	10.7	11.0	9.7	9.2	10.0
Gas Flow, lb/hr	182,300	184,600	184,700	183,900	158,300	166,100	169,300	164,600
SCFM	39,853	40,475	40,521	40,883	34,833	36,808	37,710	36,450
Gas Temp, F	335	337	334	335	340	340	340	340
Sulfur Dioxide, lb/hr	290	276	290	285	256	255	271	261
lb/10^6 Btu	-	-	-	2.96	-	-	-	2.97
ppm	732	687	720	730	741	699	723	721
Nitrogen Dioxide, lb/hr	38	39	49	42	41	42	46	43
lb/10^6 Btu	-	-	-	0.44	-	-	-	0.49
ppm	134	136	170	147	166	160	170	165
Hydrogen Chloride, lb/hr	6.3	5.1	6.9	6.1	16.7	17.4	20.3	18.1
lb/10^6 Btu	-	-	-	0.063	-	-	-	0.206
ppm	27	23	32	27	90	91	104	95
Aldehydes, lb/hr	<0.12	<0.12	<0.12	<0.12	<0.12	0.27	0.58	0.32
lb/10^6 Btu	-	-	-	0.001	-	-	-	0.004
mg/M^3	1	1	1	1	1	2.1	4.5	3.3
Ketones, lb/hr	3.6	6.6	1.4	3.9	2.7	4.0	6.0	4.2
lb/10^6 Btu	-	-	-	0.040	-	-	-	0.048
mg/M^3	25.4	46.1	10.0	27.2	22.3	31.4	46.2	33.3
Mercury Vapor, lb/hr	<0.00001	<0.00001	<0.00001	<0.00001	0.00004	0.00004	0.00005	0.00004
lb/10^6 Btu	-	-	-	0.0000001	-	-	-	0.0000005
$\mu g/M^3$	0.06	0.06	0.06	0.06	0.30	0.32	0.37	0.33

TABLE 12

PARTICULATE ELECTRICAL CHARACTERISTICS - PRECIPITATOR INLET

Fuel	COAL			COAL/d-RDF		
Stack Test Run	1	2	3	1	2	3
Date	5/19	5/19	5/20	6/16	6/16	6/17
Resistivity, 10^9 Ω-cm (300F)	12.3	3.61	6.06	1.74	4.95	12.9
Breakdown Voltage, V	2533	2600	2900	530	733	850

TABLE 13

EP TOXICITY (COMBINED ASH)

Fuel	COAL		COAL/d-RDF	EPA Maximum
Date	5/14/81	5/20/81	5/15-17/81	Concentrations*
Contaminant				
Arsenic, mg/l	2.85	3.30	<0.004	5.0
Barium, mg/l	0.20	0.20	0.27	100.0
Cadmium, mg/l	0.81	0.79	0.012	1.0
Chromium, mg/l	11.0	11.0	<0.01	5.0
Lead, mg/l	1.39	3.29	<0.03	5.0
Mercury, mg/l	<0.0001	<0.0001	<0.0001	0.2
Selenium, mg/l	<0.001	<0.001	<0.001	1.0
Silver, mg/l	0.42	0.42	<0.004	5.0

* Established as maximum concentrations of contaminants for characteristic of EP toxicity.

SECTION 7

POST-TEST INSPECTION

Following completion of the test program on June 17, Unit 3 remained in operation until the coal/d-RDF mixture remaining in the bunker was consumed. The boiler was then shutdown and inspected.

Many photographs were taken comparing ash and slagging conditions prior to the coal/d-RDF runs with the conditions following the test program.

There was evidence of clinkering along the grate line. This was a problem that had been troublesome throughout the coal/d-RDF test program. In some of the higher areas of the furnace there appeared to be more slag than had been present following operation on coal alone. However, this was not a major problem. It should be borne in mind that the mixture fired during the test program averaged in the 20-25 percent range of d-RDF by weight.

Periodically, during shutdown of coal fired boilers at the Institutions' Power Plant, it is customary to punch out the pin holes in the traveling grate that have become filled with ash during operation. This procedure was followed at the end of the coal/d-RDF firing period. Figure 22 is a photograph of a section of grate showing plugged holes.

Some of the ash punched from the holes was analyzed and found to have an ash softening temperature, (H=W) reducing, of 2,190 F. When compared with the ash softening temperatures reported in Table 5, this would imply that the synergistic effect is to reduce the coal/d-RDF mixture ash-softening temperature to that of a d-RDF ash alone. Before such a conclusion can be made, however, more data would be required.

Figure 24. Plugged Pin Holes in Travelling Grate Bar

APPENDIX A

Americology is fully owned and operated by the American Can Company, a major consumer and industrial products manufacturer with yearly sales of approximately $5 billion. Americology is part of the Recovery Systems Division.

In January, 1975, the City of Milwaukee executed a full-service contract with the American Can Company, wherein its Americology Division would build, own, and operate a resource recovery plant and dispose of the City's municipal solid waste for fifteen (15) years. The Bechtel Corporation finalized Americology's processing design and completed construction of the plant in January 1977. Americology commenced start-up operations in April of that year.

The Americology plant is located on two (2) hectares (5 acres) near the downtown business section of Milwaukee. The Americology System also includes three (3) transfer stations which collect refuse from outlying sections of the City.

The Americology plant is designed to process 1452 metric tons (1600 tons) a day of refuse, two operating shifts per day, five days per week. In April 1980, after three years of overcoming start-up problems, the Americology plant achieved its rated design capacity. It has demonstrated the capability to consistently produce at above design capacity, averaging 764 metric tons (842 tons) per 8 hour shift over one recent five month period.

The plant was designed to produce a doubly shredded, air-classified, refuse-derived-fuel through a relatively simple, low cost process, as well as reclaim ferrous, aluminum, glass and paper materials. Shredded refuse is fed directly to a zig-zag air classifier of proprietary design. The light fraction from the classifier is airveyed to a secondary Heil vertical shaft shredder. After shredding, the material is 90% minus 3/4 inch and constitutes about 55 weight percent of the as-received refuse. The refuse-derived-fuel product is then airveyed to a disengaging cyclone which deposits the product on a conveyor leading to two Heil compactors.

The Americology plant is designed to recover ferrous and non-ferrous metals and a glassy aggregate from the airclassifier underflow stream. This heavy fraction is first conveyed under

two Dings magnetic separators where ferrous is removed. Approximately 6 weight percent of the as-received refuse is recovered as a ferrous product.

After ferrous separation, the original design of Americology envisioned removal of a glass aggregate for road building purposes, and reclamation of aluminum through a CARPCO eddy current separation system. However, relatively minor operating problems associated with glass and aluminum recovery have not yet been corrected and these sub-systems are not operational.

Americology has two nearly identical processing trains rated at 70 TPH. After two years of start-up, these trains now perform at better than maximum design capacity with an on-stream factor of approximately 75%. There is no derating of the plant and the amount of equipment revamp to achieve this rate was relatively minor for the first-of-its-kind facility.

This is an abstract of the following Reference:
Mallan, G.M., "The Americology Resource Recovery System," *Proceedings of International Conference on Prepared Fuels and Resource Recovery Technology*, Department of Energy Publication ANL/CNSV-TM-60, 1981, pp. 209-219.

APPENDIX B

CO-FIRING OF DROSS FROM A REFUSE DERIVED FUEL PRODUCING PLANT WITH COAL ON A TRAVELING GRATE SPREADER STOKER AT MILWAUKEE COUNTY INSTITUTIONS' POWER PLANT

GRANT NO. R-806336-01-2

Initially, this Research and Development Grant Project was to determine the suitability of a traveling-grate spreader-stoker furnace for co-combustion of coal and dross from a resource recovery plant. Dross, or the "heavies" fraction, was defined as the material left after municipal solid waste has been processed to produce the following:

- refined refuse derived fuel (RDF) suitable for suspension firing
- a ferrous fraction for materials recovery
- an aluminum fraction for materials recovery
- a glass fraction for materials recovery

The remaining material was expected to have a high combustible content, but it would normally be destined for landfill because of its unsuitability for firing in a suspension-fired utility boiler. The denseness of dross which makes it unsuitable for suspension-firing, was thought to enhance its value as a fuel for a traveling-grate spreader-stoker fired furnace. It was thought that the dense material would tend to fall on the grate before completion of combustion rather than float up and out of the furnace as additional particulate emission.

GRANT APPLICATION

The grant application was made by Milwaukee County in the summer of 1978. The application was made in concert with officials of the American Can Company reponsible for operation of the Americology Plant in the City of Milwaukee. The research and development project was to require that facilities be installed at the Milwaukee County Institutions' Power Plant to receive, transport and distribute dross in one of the three existing spreader-stoker fired boilers. A pickup point was to be provided at the power plant to receive material as it was ejected from transport trailers. Material was to be conveyed

from the pickup point to the inlet of a pneumatic feeder. Material would be pneumatically transported to a single inlet in the front wall of the demonstration spreader-stoker fired boiler. An adjustable distributor plate at the inlet point was to be used to control distribution of the dross in the furnace. It was anticipated that the only modification to the boiler would be bending of several front wall tubes to form an opening to accommodate the distributor feed inlet. No modification was anticipated to the existing pneumatic ash handling system.

It was anticipated that the Americology Plant would be able to produce dross suitable for pneumatic transport.

At the time that the grant was awarded in September of 1978, disc screens were being added to the Americology Plant to facilitate size control of the various products from the Americology Plant.

DROSS CRITERIA

All parties involved in the Resource and Development Project agreed that for dross firing to be successful it was imperative that:

- The glass recovery system be in effective operation
- The ferrous metal recovery system be in effective operation
- The aluminum recovery system be in effective operation
- Dross received at the Institutions' Power Plant be suitable for firing with no further size reduction or processing.

The following quality criteria were selected:

- Less than 12% glass by weight
- Less than 10% metals by weight
- Less than 25% total non-combustibles by weight (including glass and metals)
- Less than 33% moisture by weight
- A nominal top size of four inches.

AMERICOLOGY PLANT PROCESS

Figure 1B schematically depicts the Americology Plant process at the time of the Grant. Dross was to be a combination of the B, E and F fractions plus the aluminum rejects. The B fraction was expected to be held to the minimum commensurate with meeting the desired dross size criterion.

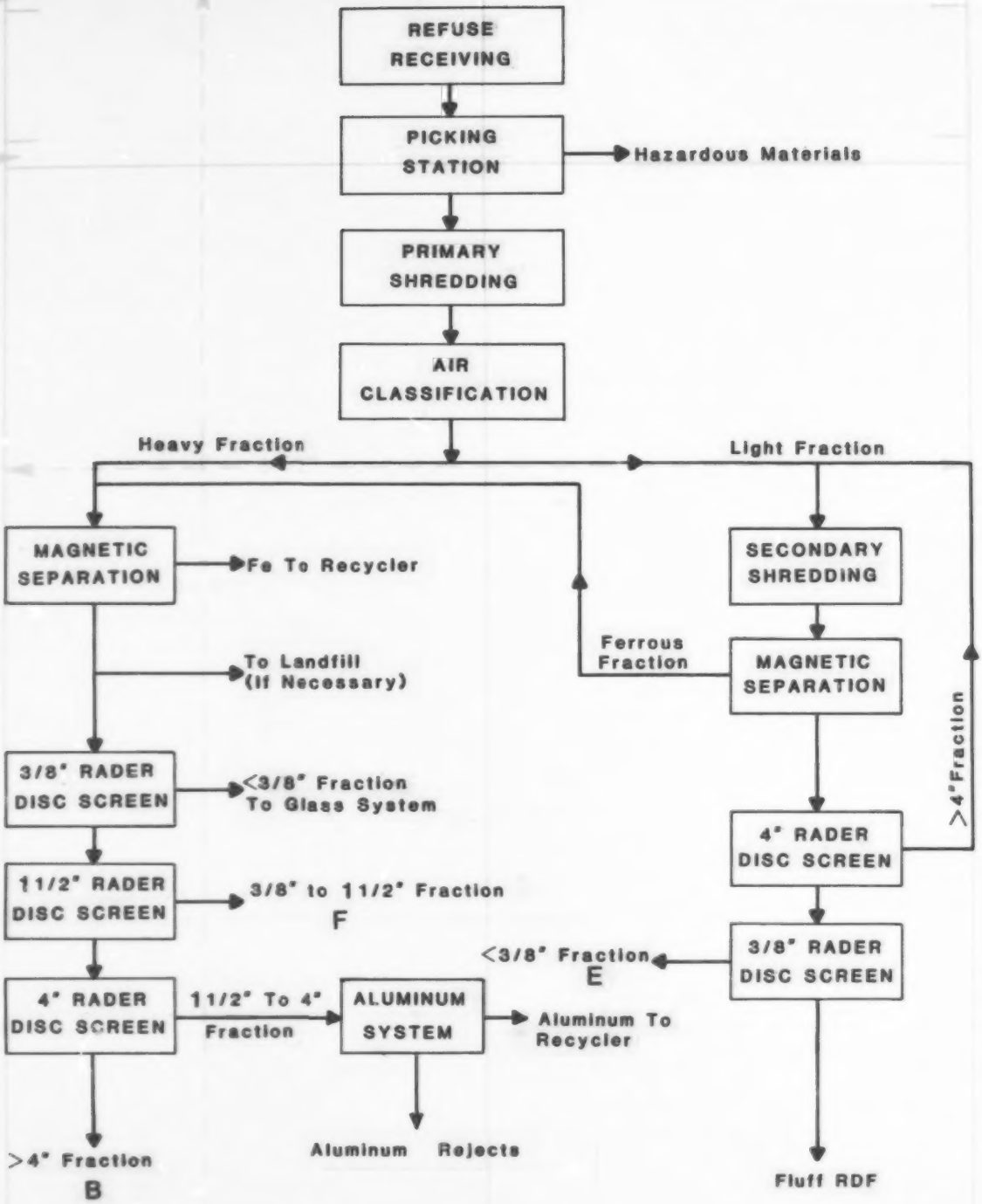


Figure 1B. Americology plant process at the time of the original grant.

Visual observations of the heavy fraction line clearly indicated that there was more oversized material than a pneumatic system could handle. Americology Plant personnel were planning modifications to operating procedures to control the quantity of oversized material when, in December 1978, an explosion in a primary shredder necessitated a total plant shutdown for a period of months. While the Americology Plant was being repaired and readied for operation, some modifications were made that were expected to enhance the quality of dross. Plant operations recommenced in November 1979.

DROSS QUALITY

Five sets of data were gathered and analyzed. Pertinent information is tabulated in Table 1B. All of the test runs were made at a reduced processing rate in order to enhance the quality of dross produced in anticipation of expected improvements in the processing system.

TABLE 1B

Date	Moisture Percent	Non-Combustibles Percent	Combustibles Percent
11-19-79	27.0	33.0	40.0
11-27-79	27.0	29.0	44.0
11-30-79	21.0	32.0	47.0
01-09-80	25.0	44.4	30.6
01-24-80	26.7	32.2	41.1

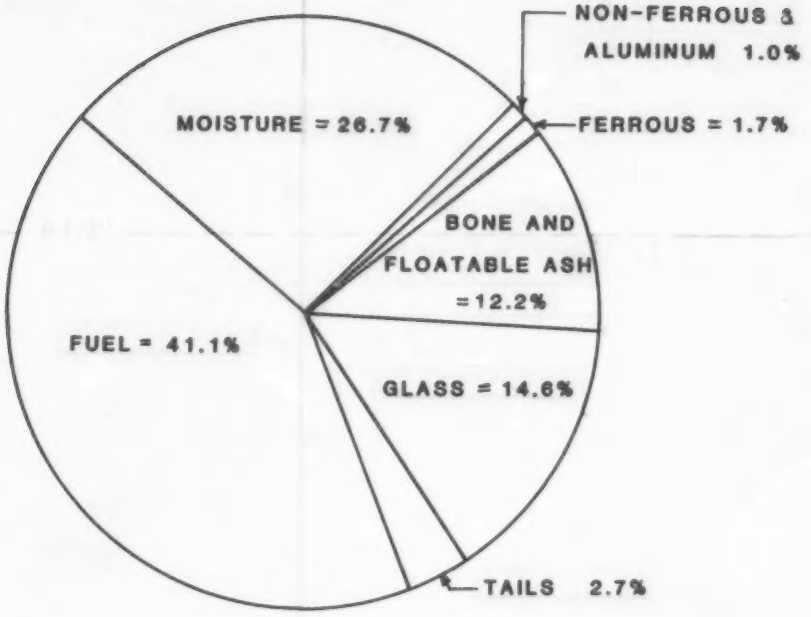
From one run to the next, improvements and adjustments were made. Thus, the test on January 24, 1980 was expected to be the best attainable. Figure 2B depicts the analysis of dross for that test run. (Note that "tails" are small stones and grit.) During this same test run on January 24, it was determined that the aluminum system was recovering about 35% of the aluminum in the entering waste stream and that the glass system was collecting about 35% of the glass in the entering waste. Close to 50% of the incoming glass and incoming aluminum remained in the dross.

It was clear that the suggested criteria for glass, total non-combustibles and nominal size were not being met. Further, it should be noted that all the test runs were made during months when refuse is relatively dry. Therefore, it could be anticipated that the moisture criterion would not be met during periods of the year when grass is prevalent in the refuse.

At this point, it was decided to determine if the F fraction alone would be suitable for use as dross. Accordingly, two more test runs were accomplished on March 31 and April 7, 1980. Pertinent data for these runs are tabulated in Table 2B.

DROSS FUEL ANALYSIS

TEST ON 1/24/80



PARTICLE SIZE (AVERAGE OF 3 SEPARATE SCREENINGS)

% PASSING	4"	78%
	2"	71%
	1 1/2"	65%
	1"	56%
	3/4"	45%
	1/2"	31%

Figure 2B. Analysis of Dross

The quantity of non-combustibles far exceeded the suggested limitation. Further, it was believed that the quantity of F fraction generated would not be sufficient for commercial consideration.

TABLE 2B

Date	Moisture Percent	Non-Combustibles Percent	Combustibles Percent
03-31-80	23.8	32.8	43.4
04-07-80	20.5	36.9	42.6

At this juncture, it was mutually agreed that the dross produced by the Americology Plant was unsuitable for pneumatic conveying and the high non-combustibles content was unsuitable for firing on a grate.

MECHANICAL CONVEYORS

Nevertheless, a comprehensive investigation was carried out to determine if it was possible to mechanically convey dross from a drop point outside the Institutions' Power Plant to the test boiler. Attempts were made to lay out conveyors to transport dross to the front wall of the boiler but insufficient space was available. Other layouts were made to transport dross to the rear wall of the boiler (notwithstanding rear wall firing was highly discouraged by the stoker manufacturer); and space conditions were found to be extremely tight. It was recognized that even if dross could be mechanically conveyed to the test boiler two major problems loomed. First, housekeeping problems in the Power Plant would be greatly increased. Second, even if conveyors could be installed and successfully operated for the test boiler (which was doubtful), it was clearly impossible to install conveyors to fire each of the three coal fired boilers. (The County's interest in the project was sustained by the potential for long-term firing of a refuse derived fuel product in the three coal fired boilers at the Institutions' Power Plant.)

DROSS FIRING ABANDONED

When it became evident that it was not practical to introduce dross to the existing boilers in the Milwaukee County Institutions' Power Plant, it was decided to abandon the Research and Development Program rather than expend the considerable capital funds required. A search for an alternative method of co-firing Americology fuel fractions at this Power Plant led to the program for co-firing of light fraction densified refuse derived fuel (d-RDF) with coal that is the subject of this report.